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DEVIATION FROM LAMBERT'S LAW AND POLARIZATION OF LIGHT EMITTED BY INCANDESCENT TUNGSTEN, TANTALUM AND MOLYBDENUM AND CHANGES IN THE OPTICAL CONSTANTS OF TUNGSTEN WITH TEMPERATURE*

By A. G. Worthing

ABSTRACT

Deviations from Lambert's cosine law for the light emitted by W, Mo, *and* Ta. The deviations for all three metals is very much of the same order. The brightness in each instance increases from the normal value at normal emergence gradually with increase in emergence angle to about 75° by about 20 per cent. From there on the brightness decreases rapidly to zero at grazing emergence. Straight filaments of circular cross-section have average brightnesses viewed normal to their axes which are about 3 per cent greater than the normal brightnesses (W 2.8 per cent, Mo 3.6 per cent, Ta 2.7 per cent). The average brightness of a filament, considering all directions, is about 5 per cent greater than the normal brightness (W 4.4 per cent, Mo 6.2 per cent, Ta 4.3 per cent).

Polarization of light emitted by W, Mo, *and* Ta. The light emitted by these materials starting with zero polarization for normal emergence increases with the angle of emergence, at first slowly, to about 95 per cent at grazing emergence. The polarizations of the light from straight filaments of circular cross-section viewed normal to their axes amount to about 20 per cent (W 19.3 per cent, Mo 20.8 per cent, Ta 18.5 per cent).

Change in optical constants of tungsten with temperature. Values obtained have depended on the variations of the emissivity and the reflectivity for the two polarized components. At room temperature 3.86 and .81 were obtained for n and k, at 1900°K 3.85 and .89 were obtained. This difference checks well with observed values of emissivity for normal emergence.

DEVIATION FROM LAMBERT'S LAW AND POLARIZATION

Introduction. In a previous paper,[1] the relative brightnesses of incandescent tungsten and carbon as functions of the angles of emission were shown to vary greatly from Lambert's cosine law. For a

*Published in abstracts in J. O. S. A. & R. S. I., *11*, p. 131, 1925, and Phys. Rev., *25*, p. 588; 1925.

self-luminous body, this law states that $b_\theta = dI/dS \cos\theta = b_0$ where b_θ and dI are respectively the brightness and the luminous intensity of an element of the surface dS of the body for light emitted at an angle θ with respect to the normal and where b_0 is the brightness viewed normally. Several references were made to the works of others[2] which had been carried out on incandescent materials. For the most part, polarization measurements of emitted radiations were made at various angles, and optical constants and brightness variations with angle were computed. In disagreement with Möller's direct measurements on platinum which showed no variation from Lambert's law, the work of the others showed considerable variations not only for platinum but also for silver. For platinum, it was concluded that the brightness should increase gradually from that for normal emission by about 20 per cent for an emission angle of about 70°. Similar results were concluded for silver. Mention should also have been made of work by Laue and Martens[3] who studied incandescent platinum. In their work as in some of the other work referred to, interest was centered in the optical constants, and the deviation from Lambert's law was ignored. Their data, however, permit of computing the deviation with the aid of standard formulae involving the optical constants.

Some three or four years ago Dr. C. V. Kent called the writer's attention to the fact that the data of the article of 1912 yielded imaginary values for the optical constants of tungsten. This suggested that gross errors might exist in the data. Since the earlier work was carried out at a time when the sources of error in optical pyrometry were not understood and when tungsten filaments were obtainable only in much less satisfactory form than now, there seemed good ground for assuming that the imaginary values computed by Kent were due to errors of measurement, and that a repetition of the work might now be justified. With the intent of obtaining reliable data for a then forthcoming summary[4] of the properties of tungsten,

[1] Worthing, Astrophysical Journal, *36*, p. 345; 1912.
[2] Provostaye and Desains, Ann. Chim. Phys., *32*, p. 112; 1851.
Möller, Ann. Phys., *24*, p. 266; 1885.
Violle, Compt. Rend., *105*, p. 111; 1886.
Millikan, Phys. Rev., *3*, p. 81 and p. 177; 1895.
Uljamin, Ann. Phys., *62*, p. 528; 1897.
[3] Laue and Martens, Physik. ZS., *8*, p. 853; 1907.
[4] Forsythe and Worthing, Astrophys. J., *61*, p. 146; 1925.

a new study of tungsten and along with it molybdenum and tantalum which is reported here, was undertaken.

Apparatus and Method. Fig. 1. shows the apparatus used and its arrangement. Lamp S and lens L were used only in the second part of this study. The specimens studied were in the form of polished ribbon filaments mounted as lamp filaments in selected lamp bulbs. In all cases the polishing had been done by rolling. The tungsten filaments were about 5 mm wide and were used as obtained from the Elkon Works, Inc. The surfaces were not strictly plane for they showed by reflected light, when a very restricted beam was used, appearances characteristic of a slightly wavy surface. However, when the surfaces were viewed through the pyrometer using reflected light as described later in the second part of this study no such detail

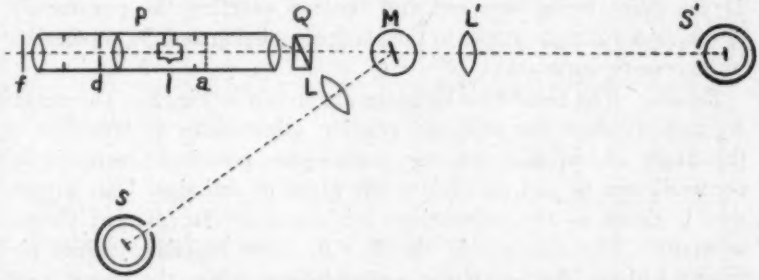


FIG. 1. *Diagram showing apparatus used in measuring the two principal polarized light components in the beams emitted or reflected by polished metal ribbon filaments for various angles of emergence or of incidence.*

S is a nearly enclosed light source, M a lamp containing a ribbon filament whose reflectivity is to be measured, Q a rochon double image prism, L a lens imaging S on the ribbon filament, P a disappearing filament pyrometer with pyrometer lamp at l, absorbing screen at a, limiting diaphragm at d, and colored pyrometer glass filter at f. S, L, and M are supported on a rotatable mount with a vertical axis at the center of M. S' and L' are positions corresponding to S and L for the determination of the unreflected brightness of the image of S. The locations of adjusting devices and of pinhole diaphragms for alignment testing are not shown.

was visible, a fact which indicated that there were no appreciable deviations from planeness greater than 2° or so. The final polishing of the molybdenum and tantalum specimens was produced by rolling them between polished safety razor blades. They were quite free from the slightly wavy surface possessed by the tungsten filament. They were filaments that had been used previously in a study of spectral emissivities and reflectivities.[5]

[5] Worthing, Phys. Rev., *25*, p. 846, 1925; *28*, p. 174, 1926.

In this work, in the case of tungsten, the main sources of error have been striations and variations in thickness of the glass of the lamp bulb. In the case of the molybdenum and the tantalum, in addition, some trouble was also experienced because the filaments had been mounted with their lengths normal to rather than parallel to the lamp axes. As a result it was very difficult to insure for large angles of emission that all pyrometer settings for any one lamp were definitely made on the same portion of filament surface.

The method of procedure is simple. With a disappearing filament pyrometer, the brightness of a certain portion of the incandescent filament was measured at various angles of emission with the adjustments such that the light admitted to the pyrometer was (1) polarized in the plane of emission (plane determined by a normal to the surface at the point being observed and the ray entering the pyrometer), (2) polarized at right angles to the plane of emission and (3) unpolarized by accessory apparatus.

Results. The results for tungsten are shown in Fig. 2. The curves $B_\perp$ and $B_\parallel$ show the observed relative brightnesses as functions of the angle of emission for the components polarized, respectively, perpendicular to and parallel to the plane of emission. Unit brightness is taken as the unpolarized brightness of the filament viewed normally. The points near the $B_\perp+B_\parallel$ curve represent values obtained without the polarizing rochon prism, while the curve itself represents the sum of the relative brightnesses of the two separate components just mentioned. Curve P represents the computed polarization, $(B_\perp-B_\parallel)/(B_\perp+B_\parallel)$, for the natural brightness as a function of the emission angle. For the $B_\perp$ and $B_\parallel$ curves, equal numbers of observations were taken on opposite sides of the normal to the emitting surface. In fact, the symmetrical adjustment of the two sets of data for the opposite sides usually served in part of the exact determination of the normal to the surface. With the hope of determining the maximum point on the $B_\perp$ curve with precision, considerable pains were taken in conjunction with the Δ points. The beam entering the pyrometer in that series was limited to a spread of about 1.3 degrees.

Results for molybdenum and tantalum similar to those described for tungsten are shown in Figs. 3 and 4.

For all three metals, the variations found were very similar. With brightness expressed in terms of the brightness of the filament viewed

normal to its surface, the relative brightness $B_\perp$ for one component was found to increase from 0.5 for normal emission to a maximum

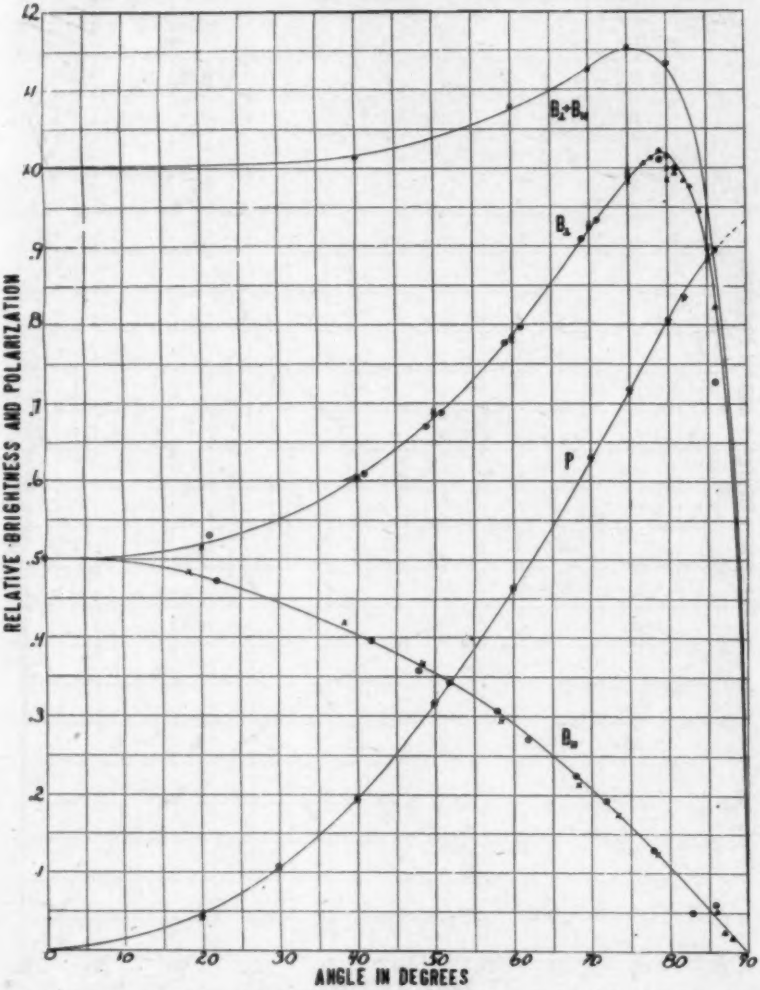


FIG. 2. *Relative brightnesses for the principal polarized light components $B_\perp$ and $B_\parallel$ and the natural light $B_\perp + B_\parallel$, and the polarization of the natural light P emitted by tungsten at incandescence as functions of the angle of emission.*

⊙ *1750°K* ⊡ *1950°K* △ × } *2470°K.*

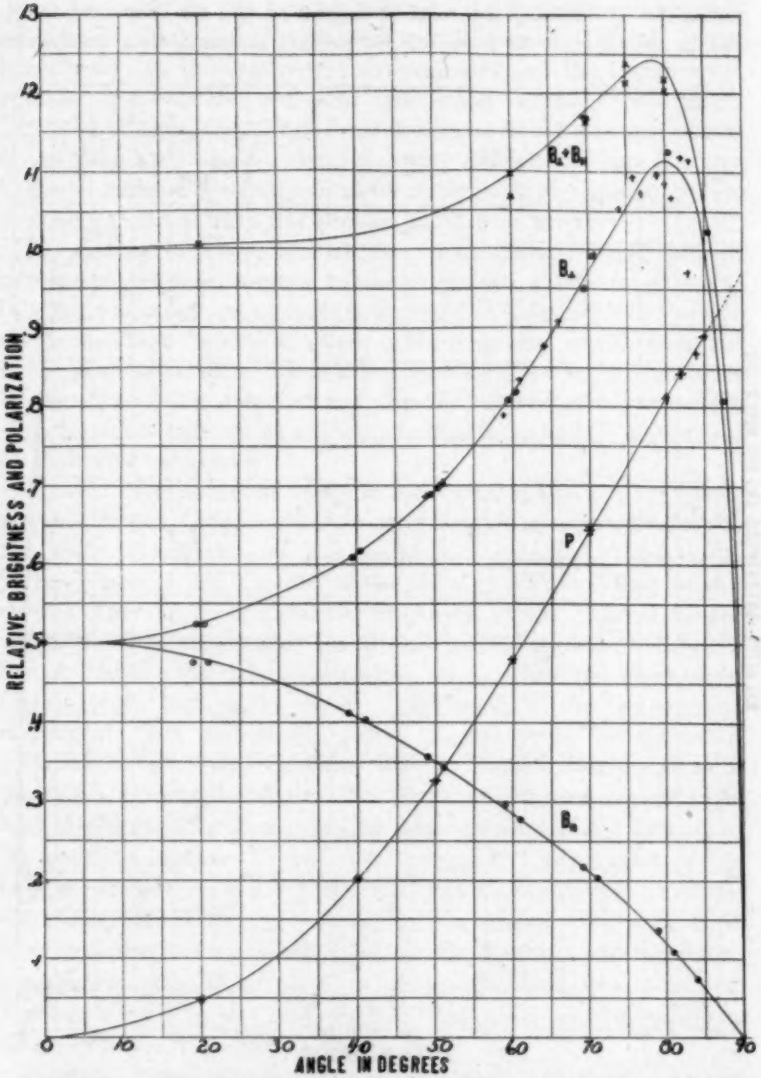


FIG. 3. *Relative brightnesses for the principal polarized light components $B_\perp$ and $B_\parallel$ and the natural light $B_\perp + B_\parallel$, and the polarization of the natural light P emitted by molybdenum at 2155°K as functions of the angle of emission. The ordinates of the $B_\perp + B_\parallel$ curve are the sums of the ordinates of the $B_\perp$ and the $B_\parallel$ curves.*

of about unity at an emission angle of about 80° and then to fall off presumably to zero at 90°. On the other hand, the relative brightness $B_{\parallel}$ for the other component was found to gradually decrease from 0.5 for normal emission to zero at 90°.

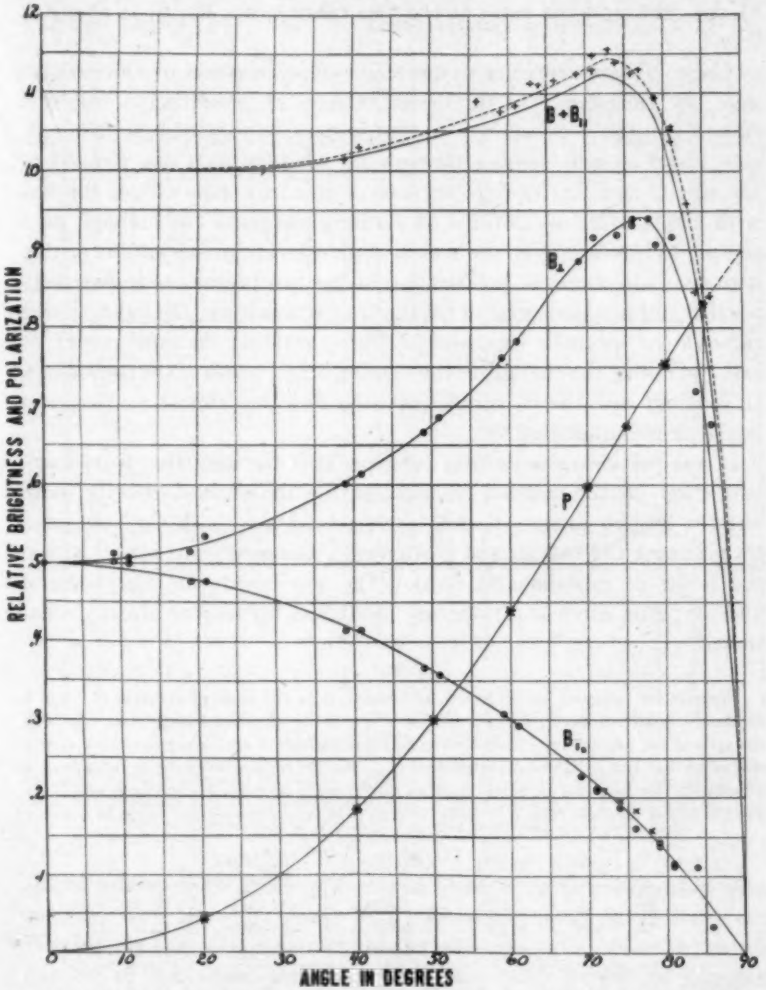


FIG. 4. *Relative brightnesses for the principal polarized light components $B_{\perp}$ and $B_{\parallel}$ and the natural light $B_{\perp}+B_{\parallel}$, and the polarization of the natural light P emitted by tantalum at 1650°K as functions of the angle of emission. The ordinates of the full line curve $B_{\perp}+B_{\parallel}$ are the sums of the ordinates of the $B_{\perp}$ and the $B_{\parallel}$ curves.*

Correspondingly, the total light emitted is partially polarized, the percentage increasing gradually from zero for normal emission to something of the order of 90 per cent or 95 per cent at grazing incidence. For an angle of 80° the polarization for tungsten is about 81 per cent, and the ratio of the two components $B_\perp/B_\parallel$ is about as 9 to 1.

These rather surprising percentages of polarization of the emitted light for tungsten may be shown readily by mounting a tungsten ribbon lamp in a closed box so that it may be rotated from the outside about an axis passing through the filament in a line parallel to the ribbon surface, by covering over a hole in a side wall of the box with a spectacle lens suitable for forming images of the filament on a screen, by placing over the lens a double image prism and adjusting it so that the planes of polarization of the two beams are respectively parallel and perpendicular to the plane of emission for the light passing through the spectacle lens, and finally by rotating the lamp about its axis and noting the changes in the relative brightnesses of the two beams. In contrast with the $B_\perp$ component, the $B_\parallel$ seems almost to disappear in the neighborhood of 80°.

It was gratifying to find for tungsten that the deviation from Lambert's law for the emitted natural light, as determined directly without the rochon prism, checked extremely closely with that obtained by summing the two $B_\perp$ and $B_\parallel$ curves. The agreement is well within the limits of experimental error. The agreements for molybdenum and tantalum are less satisfactory, doubtless for reasons already mentioned.

TABLE 1.

Showing for tungsten, molybdenum, and tantalum θ_m the angle of emission at which a filament is brightest, B_m/B_θ the ratio of that brightness to the normal brightness, $(B_{av}/B_\theta)_1$ the ratio of the average brightness for a cylindrical filament of circular cross-section viewed normal to that axis to its normal brightness, $(B_{av}/B_\theta)_2$ the ratio of the average brightness of a portion of the material as viewed from all directions to its normal brightness, and P the polarization of the light from a straight filament of circular cross-section taken as a whole.

	θ_m	B_m/B_θ	$(B_{av}/B_\theta)_1$	$(B_{av}/B_\theta)_2$	P
W	75	1.155	1.028	1.044	19.3%
Mo	78	1.23	1.036	1.062	20.8
Ta	73	1.14	1.027	1.042	18.5

Perhaps a fairer impression of the physical significance of these deviations from Lambert's law may be obtained from Table 1 where the results are shown averaged on certain bases and from Fig. 5 where the

varying brightness of uniform filaments of circular cross-section as seen from direction perpendicular to their axes, are shown as functions of the projected distances of the elements of source from the filament axes. The reality of the greatly increased brightness for certain emission angles may easily be demonstrated qualitatively with the

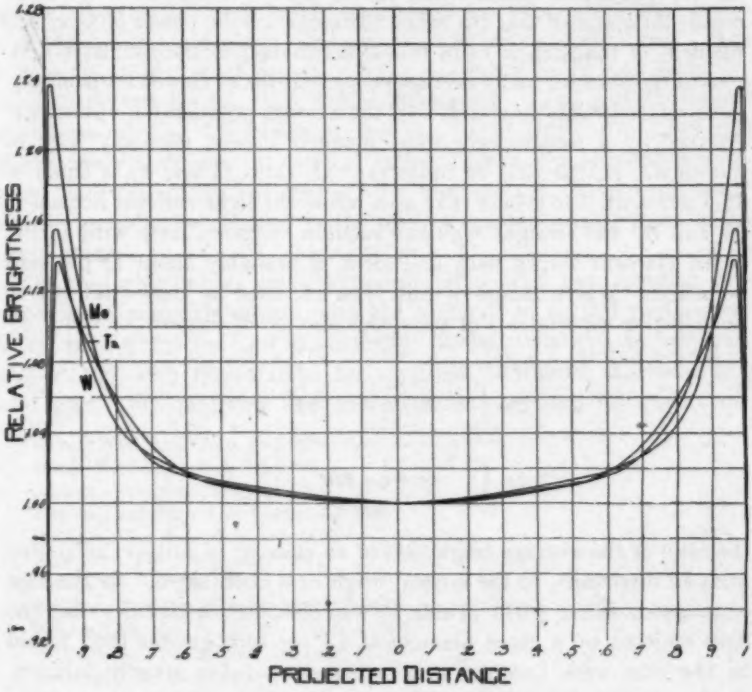


FIG. 5. *Relative brightness of the natural light emitted by straight incandescent filaments of circular cross-section of tungsten, molybdenum and tantalum as a function of the projected distance from the filament axis when viewed normally to the axis of the filament.*

aid of a lamp with a hair-pin shaped filament of large tungsten wire such as would require from 10 to 15 amperes for operation. On viewing the edge of one segment of the hair-pin loop against the central portion of the other through a telescope with a reduced angular aperture and an appropriate screen for cutting down the brightness, a difference in brightness corresponding to that diagrammed in Fig. 5 will be very apparent.

By averaging the ordinates for a particular curve of Fig. 5, the ratio of the average brightness for a uniform filament of circular cross-section viewed normal to its axis to the brightness of a portion viewed normally may be obtained (Table 1). This ratio is of interest where the temperature and certain radiating properties of the material are being related. Amounting in the case of tungsten to 1.028, it means for instance that the mean horizontal candle power of a vertical filament of tungsten is 1.028 times the product of the normal brightness of the filament by its average projected area as viewed horizontally.

By quite similar computations, the average polarization of the light emitted by a similar cylindrical filament viewed normally may be obtained. In the case of tungsten, this ratio (Table 1) is equal to 19.3 per cent. It means that as a whole the light emitted normal to its axis by the straight filament vacuum tungsten lamp with an uncoiled filament looped back and forth, is probably about 15 per cent polarized. Where lamps of this type are used as they often are in polarization experiments or tests, this may be of concern.

By evaluating

$$\frac{2\pi \int_0^{\pi/2} B_\theta \sin\theta \cos\theta d\theta}{2\pi \int_0^{\pi/2} \sin\theta \cos\theta d\theta},$$

the ratio of the average brightness of an element of surface, as viewed from all directions, to the normal brightness is obtained. In the case of tungsten where 1.044 (Table 1) was obtained, it signifies that the light emitted by a given filament is 4.4 per cent greater than would be the case were Lambert's cosine law of emission strictly fulfilled. Its importance in many problems is obvious.

These results for tungsten are different from those published in 1912, probably for the reasons noted at the beginning of this paper. As they now stand, the optical constants which they yield are no longer imaginary. The author knows of no other published results that may be used for comparison purposes.

CHANGES IN THE OPTICAL CONSTANTS OF TUNGSTEN WITH TEMPERATURE

Introduction. Generally speaking, two types of data on the radiating properties of metals for the visible region have been published,

and they are mutually inconsistent. Workers[6] who have been interested in the change with temperature of the optical constants of metals for the visible and the ultraviolet regions at temperatures below incandescence, as is well indicated by Aster's historical survey, have uniformly failed to obtain evidence of any change. The same seems to have been true of investigators who have applied the polarization method to luminous radiations at incandescence. Millikan[7] from a study of uranium glass, platinum, and silver concluded that "the reflecting properties of metals have been shown to be but little, if at all, affected by the fact of incandescence." Laue and Martens[8] found no change for platinum for the range $800°C < T < 1500°C$. From the standpoint of spectral emissivities a few experimenters[9] who have found no variations with temperature, have concluded that essentially no changes in the optical constants take place with temperature.

On the other hand, many experimenters[10] who have studied incandescent materials mostly with the methods of optical pyrometry have very definitely and consistently shown variations in spectral emissivities with temperature for tungsten, tantalum, molybdenum and gold. For platinum and nickel uncertainty and divergence of

[6]Kundt, Wied. Ann., *36*, p. 834; 1889.
Drude, Wied. Ann., *39*, p. 538; 1890.
Sissingh, Arch. Neerland., tome XX.
Zeeman, Com. Phys. Lab. Leyden, *20*; 1895.
Pfleuger, Wied. Ann., *58*, p. 483; 1896.
Kent, Phys. Rev., *14*, p. 495; 1919.
Aster, Phys. Rev., *20*, p. 349.
[7]Millikan, Phys. Rev., *3*, p. 81 and p. 177; 1895.
[8]Laue and Martens, Physik. ZS., *8*, p. 853; 1907.
[9]Holborn and Henning, Berl. Ber., 311, 1905.
Henning, Z. Instrumentenk., *30*, p. 61; 1910.
Pirani and Meyer, Elektrotech. u. Mashinenbau, *33*, p. 397 and p. 414; 1915.
Henning and Heuse, ZS. f. Physik, *16*, p. 63; 1923.
Lax and Pirani, ZS. f. Physik, *22*, p. 275; 1924.
[10]Hyde, Astrophys. J., *36*, p. 89; 1912.
Mendenhall and Forsythe, Astrophys. J., *37*, p. 380; 1913.
McCauley, Astrophys. J., *37*, p. 164; 1913.
Burgess and Watterberg, Bull. Bur. Stds., *11*, p. 591; 1914.
Worthing, J. Frank. Inst., *181*, 417, 1916; Phys. Rev., *10*, p. 377, 1917; *25*, 846, 1925; *28*, 174, 1926; Z. Physik, *22*, p. 9; 1924.
Shackelford, Phys. Rev., *8*, p. 470; 1916.
Hulburt, Astrophys. J., *45*, p. 149; 1917.
Weniger and Pfund, Phys. Rev., *14*, p. 427; 1919.
Zwikker, Arch. Neerland., *9*, p. 207; 1925.
Ebeling, ZS. f. Physik, *32*, p. 489; 1925.

opinion exist. But generally workers in this field of radiation are now agreed that variations in spectral emissivity in the visible do commonly but not always exist. The explanation for the failure of Henning and Heuse to find such variation in the case of tungsten is probably due to the unsteady character of their means of heating to incandescence. The explanation for the conclusions of Millikan and of Laue and Martens is the probable small variations with temperature if any in the metals with which they happened to work.

The present report on tungsten because of the high consistency in the data obtained, seemed to offer a good opportunity for actually determining its optical constants at both high and low temperatures and deciding whether or not some of the discrepancies in opinion could not be cleared away—therefore this discussion of optical constants.

It should be noted that tungsten mounted as a lamp filament has some very good points in its favor as a material to use. The surface of a specimen, after it has been heated in a well made lamp, is certain to be clean and in an unstrained condition. Tungsten also offers a very great temperature range for this kind of a test.

Apparatus and Method. For the determinations at high temperature, the data reported in the first part of this paper together with more data of a similar nature was used. For the determinations at room temperature, it was necessary to measure reflectivities. The apparatus is shown in Fig. 1 and is the same as that used in the first part of this study with the addition of the parts S and L which could be shifted to S' and L' by a simple rotation. The method consisted in making reflectivity measurements with the rochon prism in each of the two positions described above. Each reflectivity measurement for the filament of M required two brightness determinations. One was made of an unreflected image of S' at M, M being slightly shifted out of the line of sight. The other was made of a reflected image of S at M, the polished filament, M, serving as a mirror.

From a plot of such reflectivity data (Fig. 6), it is simple to determine the angles of principal incidence Φ and of principal azimuth Ψ. The former is to be identified with the angle at which the polarization of the reflected light is a maximum, the latter by the following relation for the condition of principal incidence

$$\left[\tan^2\psi = \frac{R_\perp}{R_\parallel}\right]_{\phi=\Phi}$$

where $R_\perp$ and $R_\parallel$ are the reflectivities for the material of the filament at M for the two beams which are polarized respectively perpendicular to and parallel to the plane of incidence. Given these two angles, the optical constants may be computed in accord with optical theory.

For computing optical constants at high temperatures, it is necessary to know the absolute values of the spectral emissivities rather than the relative values which are plotted in Fig. 2. It was therefore necessary in this work to make use of separately determined normal emissivities to correspond to the temperatures[11] chosen. This may seem

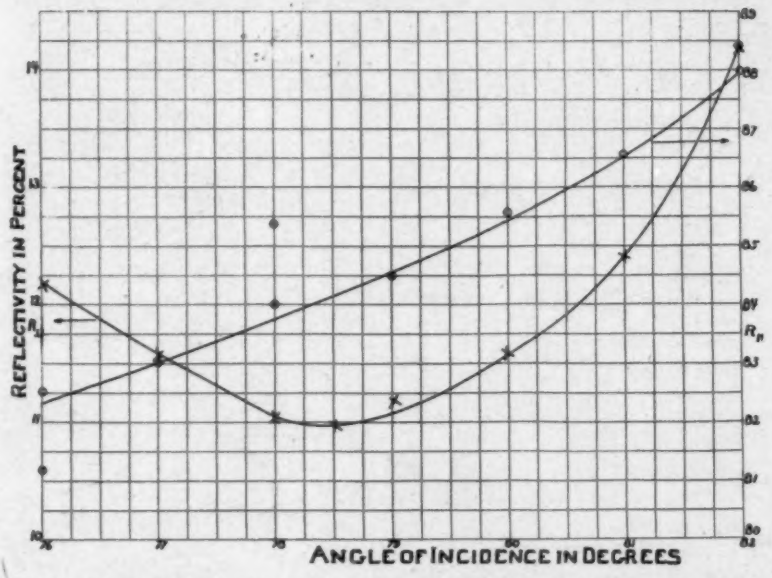


FIG. 6. *Polarization produced by reflection from tungsten at room temperature for angles of incidence approximating the angle of principal incidence.*

at first like assuming the result to be obtained, but it will be shown that this does not limit the conclusion reached. Using these normal emissivities, absolute values follow for the emissivities at other angles, then absolute reflectivities and finally Φ and Ψ as for the low temperature case.

In the calculation of the optical constants n, and k, the formulae used were

[11]Worthing, loc. cit, Phys. Rev., *10*, p. 377; 1917; Forsythe and Worthing, Astrophys. J., *61*, p. 146; 1925.

$$n = \frac{\sin \Phi \tan \Phi}{\sqrt{1+k^2}\left[1 - \frac{1}{2}\frac{\sin^2 \Phi}{n^2(1+k^2)}\frac{1-k^2}{1+k^2}\right]}$$

$$k = \frac{\tan 2\psi}{1 + \frac{\sin^2 \Phi}{n^2(1+k^2)}}$$

Computed values for n and k, together with the values of e_n, Φ, and $R_\perp/R_\parallel$ (i. e. $\tan^2 \Psi$) are shown in Table 2. There are also shown computed values for e_n as obtained from the well known formula

$$e_n = 1 - \frac{n^2(1+k^2) - 2n + 1}{n^2(1+k^2) + 2n + 1}.$$

Though no emissivity is shown as assumed for the two room temperature cases, the measurements of $R_\perp$ and $R_\parallel$ actually made were consistent with the value 0.470 which had been obtained previously, in part on the filament used in this study.

TABLE 2. *Data leading to and results for the optical constants of tungsten for various temperatures* ($\lambda = 0.665\mu$)

Temperature	Room	Room	Room *	2250°K	1700°K	1700°K	1700°K	1900°K †	1900°K ‡
Emissivity (measured)	.....	.....	.470	.430	441	441	441	.437	(.470)
Φ	79.2°	78.4°	78.8°	79.5°	78.4°	79.5°	79.6°	79.2°	79.2°
$\tan^2\Psi$	.134	.130	.132	.135	.146	1.69	.161	.152	.15
k	.82	.80	.81	.82	.87	.94	.92	.89	.59
n	3.92	3.82	3.86	4.03	3.66	3.87	3.89	3.85	4.35
(e_n computed)	.452	.470	.461	.446	.463	.419	.425	.437	.456
Discrepancy in e_n	+.018	.000	+.009	−.016	−.022	+.022	−.016	.000	+.014

*This represents an average at room temperature.

†This represents an average of the high temperature values.

‡This represents an average for high temperature values on the assumption that the measured emissivity at room temperature is also the emissivity at incandescence.

A first inspection of the table is likely to give the impression that no change in optical constants is shown. If attention is given to the averages only, we have for n and k 3.86 and 0.81 at room temperature to compare with the 3.85 and 0.89 at the high temperature. This variation seems small, but in the computation it is sufficient to account for a computed e_n of 0.461 in one case and of 0.437 in the other place, a variation of appreciable magnitude for optical pyrometry.

It is significant, however, that the computed values of e_n agree well with the original observed values and that these differ from each other. When 0.470, the room temperature emissivity, is assumed for the incandescent temperature, not only does the computed e_n fail to check the originally assumed e_n but also the computed n and k then differ markedly from the n and k obtained for room temperature, as shown by the last column of Table 2. The situation is the following. If no change in optical constants with temperature is assumed at the outset, the derived values for n and k then show a decided change with temperature. If, on the other hand, the optical constants are assumed to vary with temperature in accord with emissivity measurements, the derived values for n and k then show only a small dependence on temperature, but what dependence there is is in accord with measurements.

The conclusion that must be drawn is that there is a change, though not very pronounced, of optical constants with temperature. Further attempts will be made to secure data under more satisfactory conditions for the more careful testing of this conclusion.

The accuracy of the molybdenum and the tantalum data does not justify an attempt to use them similarly.

The writer is indebted in this work to Miss Pauline Perkins and Mr. John Kirschner for aid in the experimental work.

RESEARCH LABORATORY,
NELA PARK, CLEVELAND, OHIO.

Control of Optical Surfaces.—In this instalment, the fifth in a discussion of the subject, the modifications of the Foucault knife edge test introduced by Ritchey, by Cojan, and by others are discussed. Ritchey's method involves the use of an opaque screen with narrow openings exposing diametrically opposite portions of a zone. The knife edge is adjusted for equality of brightness of the penumbra as seen through the two openings. Some of the objections to the method were removed by Cojan, who photographed the appearances instead of observing them visually and measured the plates on a microphotometer, thereby increasing the precision obtainable. In order that the method may be made to give full quantitative data the author applies it in a manner (the method of limited penumbras) that leads to the profile of incurvation, from which the tangential and the normal profiles may be deduced. The method may be applied in the study of either spherical or aspherical waves. [M. G. Yvon; Revue d'Optique, *4*, pp. 401–426; 1925.] G. W. MOFFITT

Photoelectric Investigations of Liquid Surfaces.—Apparatus is described for studying the photoelectric effect of free liquid surfaces, together with devices for cleansing the surfaces by overflow. A mercury lamp with NaF window permitted measurements beyond the ultraviolet limit of the transparency of quartz. Fresh water shows no measurable effect; after standing it becomes photo-electrically active, probably because a solid surface (dust) is formed. HCHO easily polymerizes to trioxymethylene, which forms a solid surface and shows photoelectric effect, with the fatigue phenomena characteristic of solids. Many inorganic salts were investigated in aqueous solution. Only the ferrocyanides are active; they show fatigue due to some colloid which collects on the surface; it can be removed by ultrafiltration, but forms again, slowly in the dark, more rapidly in the light. By changing the concentration and by experiments using common ion effects, the activity is shown to be proportional to the concentration of undissociated molecules. The author believes that only the outermost layer of molecules contributes to the photoelectric emission. If so, the presence of undissociated molecules contributes to the photoelectric emission. If so, the presence of undissociated molecules in this layer is demonstrated. Dissolved volatile substances have little influence on the activity of ferrocyanide solutions provided their vapors are blown away so that the incident light is not absorbed before reaching the solution. A number of solid salts are found to possess considerable activity, although their aqueous solutions were inactive. Solid ferrocyanides are especially active.—[Wilhelm Zimmermann; Ann. d. Physik, *80*, pp. 329–48; 1926.] A.E.R.

Absorption Spectra of Condensed Nuclear Hydrocarbons.—Previous work on absorption spectra of many coal-tar hydrocarbons has been vitiated by impurities. Phenanthrene and fluorene were freed from anthracene by refluxing xylene solutions by heat from a quartz mercury arc; the light polymerizes anthracene. Using a Hilger spectrophotometer and condensed Cu spark, the authors obtained absorption spectra of phenanthrene, fluorene, anthracene, hydroanthracene, bisdiphenyl-ethylene, and chrysogen. Chrysogen (structure unknown) ash a spectrum of the polynuclear hydrocarbon type, and has an anthracene nucleus.

Constant frequency differences of about 142 and 101 waves per millimeter characterize these spectra. The difference 142 is correlated with differences occurring in the spectra of benzene and naphthalene. Relations to infrared spectra: Benzene bands at 3.25, 6.75, and 12.95μ are due to the CH: group. Ethylene has infrared bands with spacings about 47.4 waves per millimeter due to C:C. Note that 47.4 times 3 equals 142. The difference 142 may be due either to CH: or C:C.—[Norman Stuart Capper and Joseph Kenneth Marsh; J. Chem. Soc., *129*, pp. 724–30; 1926.] A.E.R.

MEASUREMENTS OF THERMOPHOSPHORESCENCE OF GLASS PRODUCED BY RADIUM RADIATION[1]

By R. E. Nyswander and S. C. Lind

ABSTRACT

Thermophosphorescence of glass colored violet by previous exposure to radium emanation. (1) Visible light emitted by the glass when heated to temperatures around 115° to 255° C was measured with a polarization photometer, using radium luminous paint as comparison source. The total quantity of light emitted by equal areas of similarly radiated glass of the same thickness was found by integration of the curves to be constant, independent of the temperature or rate of light emission. The rate of decrease of light intensity at constant temperature approximately fits the equation for second order chemical reaction $dx/dt = k(a-x)^2$. The values of the velocity constant k increase with temperature in accordance with the van't Hoff equation $\log K = C - a/T$. The temperature coefficient is somewhat lower than that characteristic of chemical reaction but higher than for most purely physical reactions. (2) *Heat radiation.* Measurements made with a Coblentz silver-bismuth thermopile failed to detect any increased heat radiation accompanying the luminescence.

The thermophosphorescence of glass previously exposed to radium radiation has been investigated qualitatively by Meyer and Przibram[2] by Lind[3] and by Clarke.[4]

The purpose of the present investigation is to measure the intensity of the light emitted by glass, previously exposed to the rays of radium, when the glass is heated to temperatures at which thermophosphorescence takes place. The measurements were confined to glass which had colored violet; Clarke claims that all specimens of this variety contain manganese, while other varieties do not.

A further object of the investigation was to study the time rate of diminution of light intensity at various constant temperatures and to determine the temperature coefficient of the reaction producing light.

As a preliminary to the measurement of light radiation, a large number of radiated glass specimens were tested for heat radiation. A linear thermopile of very small heat capacity of the silver-bismuth type was constructed according to Coblentz.[5] Tests were made to determine whether at the temperature of thermophosphorescence there was any evolution of heat accompanying the luminescence. The

[1] Abstracted in the Physical Review, *23*, p. 296; 1924.
[2] Meyer and Przibram, Sitz. Akad. Wiss. Wien, *121* (IIa), p. 1414; 1912.
[3] Lind, Jour. Phys. Chem., *24*, p. 437; 1920.
[4] Clarke, Phil. Mag., *45*, p. 268, p. 735; 1923.
[5] Coblentz, Bull. Bu. Stds., *9*, p. 7; 1913.

glass was heated in a small electric furnace, well insulated to protect it from heat variations through the walls. An iron tube with the thermopile at one end extended into the furnace and was pivoted so that it could be brought into line with the glass specimen or turned to receive the radiations from the heated interior. The end of the iron tube entering the furnace was closed with a fluorite window to prevent convection currents. A small mica window in the front of the furnace made it possible to observe the luminescence of the glass. By alternate observations on the glass and the interior, comparative measurements of the radiation of the glass with that of the interior of the furnace, taken as a standard, were made. The results of these observations indicated that there was no radiation of heat that could be definitely ascribed to the phenomenon of thermophosphorescence. The observations were not only carried as far as the temperatures of luminescence, but were continued up to temperatures of 510° until all the color of the glass had been destroyed. No heat radiation peculiar to the disappearance of color was noted.

The intensity of the light radiated from the glass is of such a low order that when focused upon a photographic film for as much as three minutes no visible impression is produced. A potassium photoelectric cell, when substituted in place of the photographic film, failed to produce readable deflections when connected in circuit with a galvanometer of 10^{-9} ampere sensibility. The cell was used with the highest electromotive force that could be employed without producing a drift of the galvanometer needle.

A modified form of polarization photometer, to be described in another paper, proved to be entirely adequate for quantitative measurements of the relative light intensity. The arrangement of the apparatus is shown in Fig. 1. A small electric furnace was constructed from a muffle which was wrapped with heat resisting wire and then packed in a box with asbestos plaster to guard against losses of heat and rapid fluctuations of temperature from conduction through the walls of the furnace. The specimen of glass to be heated was placed at S in the furnace. The front of the electric furnace was closed with a close-fitting cover of insulating material and a mica window permitted observations of the luminosity to be made through the tube T. The polarization photometer was mounted at the side of the tube T and consisted essentially of two nicol prisms N_1 and N_2. Prism N_2 was fixed, while N_1 could be rotated about its axis, the angle of rotation being measured

by a pointer and a graduated scale. A source of light at L acted as a standard of illumination. The intensity of the light after passing through the two nicol prisms is proportional to $\cos^2\theta$, where θ is

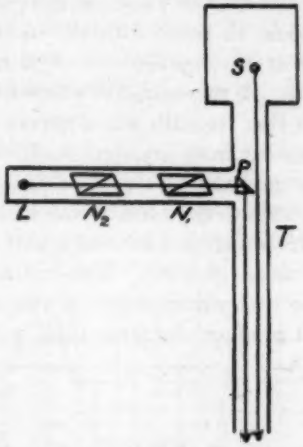


FIG. 1. *Diagram of apparatus showing arrangement of polarization photometer and furnace.*

the angle between the principal sections of the two nicol prisms. A right angled glass prism at P reflected the beam through the tube T alongside of the light from the source S of the luminescent glass. The

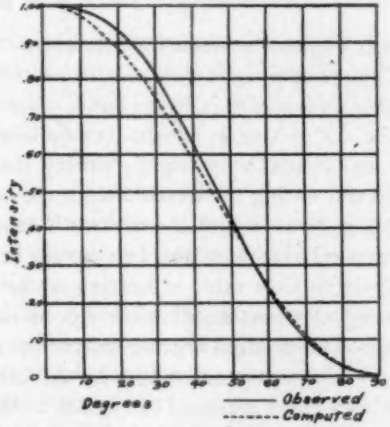


FIG. 2. *Variation of the intensity of transmitted light as dependent upon the angle between the principal planes of two nicol prisms.*

polarization photometer may be calibrated by the $\cos^2\theta$ curve or by means of a photoelectric cell. The curves of Fig. 2 show how closely these methods of calibration agree. The results of the work described in this paper were obtained from the observed (solid line) curve.

An adjustable rheostat in series with the furnace made it possible to heat the specimen at any desired rate or to hold the temperature constant at any point. A thermometer extended down through the top of the furnace so that its bulb was adjacent to the heated glass. Measurements of luminous intensity were made throughout the range of thermophosphorescence and plotted as a function of the time.

The glass used for these experiments was in the form of tubes of about 7.5 mm diameter which had formed a part of a vacuum system for the collection of radon (RaEm). This insured uniformity of exposure of the glass to the radium rays. If two similar specimens of glass equally radiated produce the same total quantity of light when

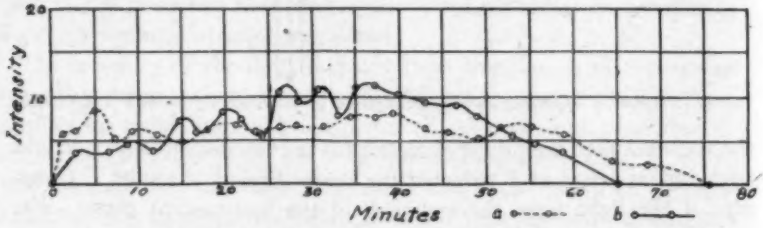


FIG. 3. *Total quantities of light emitted by two exactly similar specimens of glass.*

heated, then curves plotted between light intensity and time should have equal areas independently of temperature or the rate of heating. How accurately this assumption is borne out is shown in Fig. 3. The rates of heating in the two cases shown (curves *a* and *b*) were very different; tube *a* was heated very rapidly during the first part of its luminescent period and during the second half of the period the heating was slow. To obtain curve *b* just the reverse heating methods were employed. The general shapes of the two curves are roughly determined by the respective time rates of heating in the two cases. The duration of luminescence continued about eleven minutes longer in curve *a*, on account of the gradual heating toward the end of the period of light emission. The temperature ranges are as follows: for curve *a* from 112° to 258° and curve *b* from 114° to 236°. Small fluctuations in the shapes of the curves indicate variations in the rate of heating of the furnace, since no effort was made to maintain a constant rate

of temperature change. The areas of curves *a* and *b* as measured by a planimeter are practically equal, the variation from the mean being about 1/3 per cent. Numerous curves were measured for similar specimens of glass equally exposed and in all cases the areas were the same. The values of the intensities of the light as indicated in the curves are relative values obtained from the calibration curve of the photometer and then multiplied by a factor of three to increase the values to a convenient scale.

In Fig. 3 it is shown that the shape of the curve is dependent on both the time and temperature as variables. To eliminate the effect of change of temperature, the glass was heated very rapidly to some temperature within the range of thermophosphorescence and held at this temperature while measurements of light intensity were made.

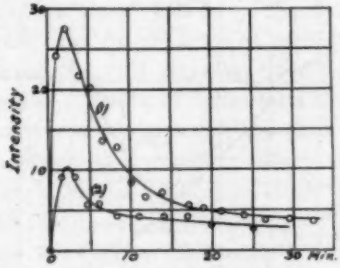


FIG. 4. *Showing rate of decay of the intensity of thermophosphorescence of two different specimens of glass at 130°C.*

The rate of change of luminosity with time at a constant temperature of 130°C is shown in two curves in Fig. 4, which are typical constant temperature curves. The first was obtained from a sample of glass exposed to radium radiations about nine months prior to the measurements of luminous intensity, while for curve 2 and all other glass tested, the period between radiation and light measurement was about three years. The differences in areas of these two curves is probably due to the slow loss of thermophosphorescence at ordinary temperatures over long periods of time.

The shapes of the curves in Fig. 4 suggest an exponential law for the rate of diminution of thermophosphorescence and are quite similar to the curves expressing the rate of chemical reaction with time. It therefore seemed advisable to apply to these results the velocity equations for both a first order (monomolecular) and second order (bimolecular) reaction. While the values of the velocity constant *k*

for first order reaction were roughly uniform, yet much better agreement was obtained with the latter equation. Both in the first and second order equations a represents the total quantity of light emitted from any initial time t_0 to the end of the emission; x is the quantity of light already emitted up to any time t; $a-x$ is therefore the quantity of light yet to be emitted, both a and x, taken from the time versus intensity curves, are measured in arbitrary units. The quantity k is the velocity constant of chemical reaction. In the second order equation, $dx/dt=k(a-x)^2$, the term $(a-x)^2$ constitutes the tendency

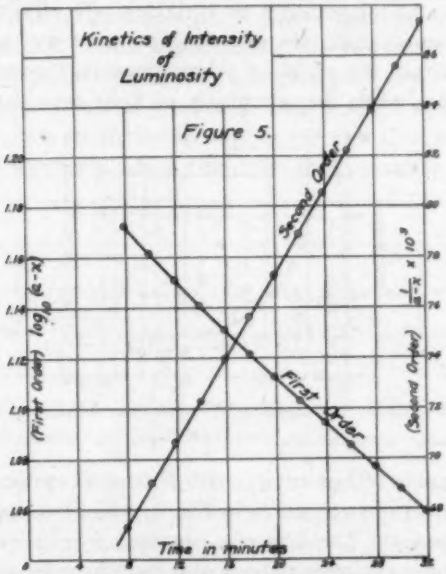


FIG. 5. *Rate of light emission as dependent upon the square of the light to be emitted.*

or driving factor and hence is put proportional to dx/dt, the rate of emission. By plotting values of $1/(a-x)$ against t, a straight line is obtained from which the value of k may be determined. In Fig. 5 are plotted values of t and $1/(a-x)$ taken from the mean value of the curves of Fig. 3 and curve 2 of Fig. 4, all from exactly similar specimens of glass. The velocity constant k as found from Fig. 5, is .00083.

In securing the data for the radiation curves the element time is measured from the instant luminosity is first observed. The luminous radiation starts quite suddenly and with sufficient intensity to permit making observations with considerable accuracy both for the total

radiation and the constant temperature curves. However, at the end of the period of luminosity the light intensity decreases very gradually and finally falls below the extinction value. All radiation curves were secured at night in a room darkened by blinds to shut out the light from the night sky. The light standard used in the photometer was a luminescent radioactive preparation of zinc sulphide. No difficulty due to difference in color was experienced, first because the two sources of light are very much the same, and secondly, because most of the light radiations were below the color threshold value. Integrating the second order equation we get $k=x/ta(a-x)$. By substituting light values for a and $a-x$ in this equation, a series of values of k were determined which did not agree exactly with the value .00083 from the curve of Fig. 5. The most probable source of error seemed to enter in the measurement of the time t, and so a "step by step" method was employed, which would entirely eliminate an error in the measurement of the time of beginning of light emission. Such an error is in part unavoidable because the emission of light starts some time before the light actually becomes visible; however, the recorded times may be corrected by the addition of a constant which can be determined. Another source of error in the isothermal curve might enter in the measurements of the maximum light emission. This is more marked in the values of k for the higher temperatures, since a comparatively large quantity of light is given out quite suddenly as the heated glass first reaches the constant temperature, and then the luminosity decreases very rapidly. It is posssible that an error might be introduced in the measurement of this sharp maximum. There is also the difficulty of making accurate photometric comparisons of such extremely weak sources of light when the intensity is changing rapidly. In securing the isothermal curve there is some difficulty in maintaining the furnace at constant temperature over a long period of time and a small change in temperature will produce a considerable change in the rate of light emission.

The following step by step equation was found from the foregoing equation of k by employing two sets of values for t and x, namely,

$$k = \frac{1}{t_2 - t_1}\left[\frac{x_2 - x_1}{(a - x_2)(a - x_1)}\right]$$

In Table 1 the value of a is the mean value of the curves a and b in Fig. 3, and x was measured from the constant temperature curve (2) of Fig. 4. The recorded values of the velocity constant k were found

by the stepwise equation and the mean value agrees with the value as determined from the curve of Fig. 5.

TABLE 1.

$a = 16.937$

t	x	k
7.9 min.	2.075	
9.9	2.441	.00085
11.9	2.785	.00084
13.9	3.105	.00082
15.9	3.413	.00082
17.9	3.709	.00083
19.9	3.991	.00082
21.9	4.261	.00082
23.9	4.520	.00082
25.9	4.770	.00083
27.9	5.103	.00084
29.9	5.254	.00086

a and x in arbitrary units.

If I represents the intensity of light emitted at any time t as may be found from the isothermal curve, it may be shown from the second order chemical equation that $1/\sqrt{I}at$. This relation when plotted gives a straight line. In Fig. 6, the values of I and t were taken from curve (1) of Fig. 4.

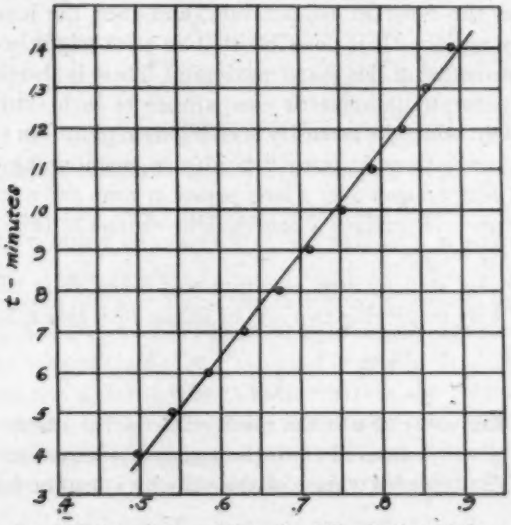


FIG. 6. *Relation between the intensity of illumination and time.*

The values of the constant k for most of the specimens tested showed a downward trend with time. This may however be due in part to the source of error already discussed. Even were the agreement more complete it would not at all follow that the reaction is necessarily chemical in nature, since any cause that would have led the momentary rate of emission to be proportional to the square of the quantity of light remaining to be emitted, would have satisfied the same equations. In fact, the application of the second order equation to chemical reactions usually implies that actual diffusion takes place and it is rather difficult to suppose rapid diffusion within a solid. As has been suggested by Amberson,[6] the second order equation would seem to apply to the general theory of electron displacement as the source of luminescence. The primary reaction in the glass is produced by the radium radiation and consists of a certain electron displacement. The reverse reaction producing light emission takes place upon the return of these electrons (or negative ions as the case may be), this, of course, requiring the recombination of two different things, the positive and negative ions. The rate of this recombination is measured in terms of emitted luminescence originating from vibrations taking place through mean positions which are fixed as contra-distinguished from diffusion. The number of effective encounters ought to depend upon the product of the concentration of the two things, and when the two, as in this case, are equal to each other, upon the square of the concentration.

To determine the change of the constant k with change of temperature, similarly radiated samples of glass were tested at four temperatures, and the following respective mean values of k were found: 120°, $k=.00046$; at 131°, $k=.00074$; at 145°, $k=.00141$ and at 159°, $k=.00263$. In securing the value of the velocity constant k it is fortunately not necessary to use separate pieces of glass for determining the quantities a and x, for where glass of varying thickness is used, the results so obtained cannot be accurate since the intensity of the radiated light depends upon the thickness of the tube. To obviate this difficulty, each specimen is heated to the temperature at which k is to be determined, held at this temperature long enough to secure a series of observations, and then the heating process is continued until luminescence is exhausted and the total area of the curve measured.

A simple relation between the values of k and temperature is an empirical one based largely upon the experimental fact that the value

[6] Amberson, Journ. Gen. Physiol. *4*, p. 517, p. 535; 1922.

of the velocity constant in most chemical reactions is found to double for each 10° rise in temperature. The value of k above do not bear out this relation, however; the temperature coefficients are more nearly in agreement with those characteristic of chemical reactions than could be expected from most purely physical phenomena. A better test for the values of k than is expressed by the foregoing relation is to be found from the application of the van't Hoff equation[7] $\log k = C - a/T$

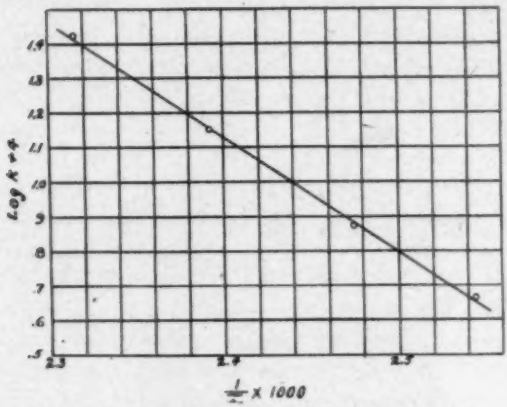


FIG. 7. *Variation of velocity constant with temperature.*

where C and a are constants (C being independent of temperature) and T is the absolute temperature. If we plot as in Fig. 7, the values of the logarithm of the velocity constant against $1/T$, a straight line is obtained. For convenience in plotting, $\log k$ is increased by 4 and $1/T$ is multiplied by 1000. The equation of this straight line is found to be $\log k = 5.06 - 3.30 \cdot 10^3/T$.

We are indebted to Dr. D. C. Bardwell for looking over this manuscript and for assistance in making some of the calculations.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF DENVER, (R. E. N.)

FIXED NITROGEN RESEARCH LABORATORY,
WASHINGTON, D. C., (S. C. L.)

[7]For a complete derivation, see Nernst's Theoretical Chemistry, fourth English Edition, p. 718; 1916.

LINKS CONNECTING FLUORESCENCE AND THE LUMINESCENCE OF INCANDESCENT SOLIDS

By E. L. Nichols

Thirty-five years ago, in June 1891 the present writer in collaboration with B. W. Snow[1] called attention to the remarkable departures of zinc oxide from the laws of ordinary temperature radiation.

Since these departures were in the nature of an *excess*, the then new term *luminescence*, proposed by Eilhard Wiedemann for any type of radiation not the direct result of temperature, was used to designate them.

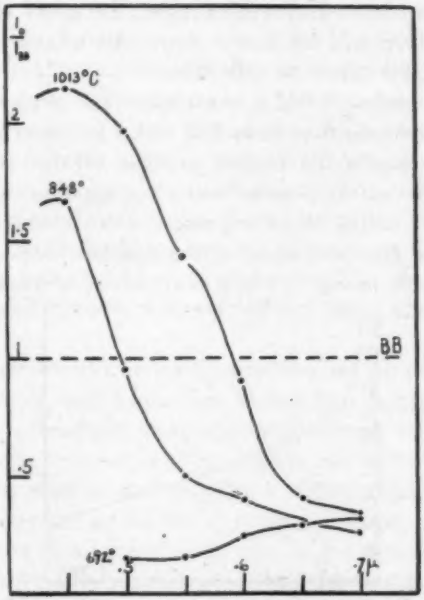


FIG. 1. *Development of selective radiation (luminescence) from data of 1891.*

It was established at that time that the effect was selective, as to wave length, was confined to a rather narrow range of temperatures and was subject to fatigue: statements which may be illustrated by the following figures made from measurements in the course of that investigation and later.

[1]Nichols and Snow; Phil. Mag., *5*, *33*, p. 21; 1892.

Fig. 1 gives the distribution of brightness in the visible spectrum of glowing zinc oxide at three temperatures in terms of that of a black body taken as unity.

The dotted horizontal line *BB* represented normal black body radiation and ordinates are the ratio I_0/I_{BB} where I_0 is the intensity of the oxide.

A white oxide is normally a poor radiator, which condition is expressed by the curve for the radiation at 692°C but at 848° and 1013° we see the development of a band having its crest in the violet, with a suspicion of a shoulder in the yellow which suggests a second overlapping band. The intensities at the crest run more than twice the corresponding black body brightness, whence the designation of the effect as luminescence. In previous papers are many further examples and Fig. 1 is given only because it represents what are thought to be the earliest measurements of this effect.

The similar outburst which constitutes the extraordinary actinic intensity of the magnesium flame and which has been shown to be due to the luminescence of the nascent particles of MgO within the flame was later studied at the present writer's suggestion by F. J. Rogers.[2]

Fatigue. The falling off in brightness which characterizes ordinary luminescence is also a feature of the luminescence of incandescent solids. The curve in Fig. 2 which is from our measurements of 1891

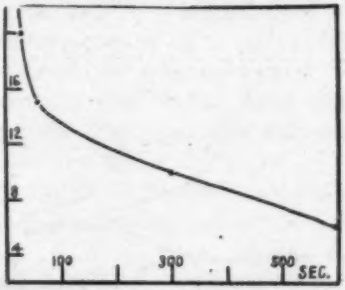


FIG. 2. *Fatigue in the brightness of ZnO at 1000°C during incandescence (Taken for .45μ)*

refers to the violet end of the spectrum but similar curves may be plotted from the existing data for any chosen wave length.

The phenomenon was once familiar to every user of the lime light in the rapid fading away of that source of illumination, requiring frequent turning of the cylinders of lime so as to expose new surfaces

[2]Rogers; Am. Jour. Sci., *43*, p. 301; 1892.

to the flame. Measurements [3] made of the decay of the lime light for different parts of the spectrum led to a result similar to that for ZnO.

In this case it was found that complete return of the material to its original state occurred upon resting; a property which is also characteristic of ordinary fluorescence.

Fatigue while unexposed, is another property common to both types of luminescence here under consideration. That the glow from the newly formed particles of MgO in a flame of burning magnesium far exceeds that to be obtained if the oxide be collected and then reheated to the same temperature is well known. Similarly many fluorescent crystals, when newly formed, exceed in brillancy under excitation their subsequent intensity.

Sensitiveness to heat treatment may be referred to in this connection as a trait common to both types. In a paper on the incandescent oxides it has been shown[4] that incandescent beryllium oxide may be greatly modified as to its brightness at a given temperature by modifying the temperature to which it had previously been brought.

Of the four attributes thus far considered, excess of brightness alone would lead to the certain classification of the radiation of these oxides as luminescence under the broad definition of Wiedemann. The others, i. e. fatigue and recovery, sensitiveness to heat treatment, selectivity of spectral structure are suggestive of a close relationship to ordinary fluorescence—taken collectively they are *very strongly* suggestive.

A conclusive test would be the precise comparison of wave lengths such as are possible with radiations having line spectra. To detect and locate the submerged components of broad banded spectra, particularly where luminescence is superposed upon more or less powerful incandescence is obviously more difficult than the study of the fluorescence spectra of bodies at ordinary temperatures.

Shortly after the discovery of excitation by the action of the hydrogen flame,[5] however, Dr. Howes[6] undertook the analysis of the glow thus produced. The mesh of a disk of fine brass gauze was filled with air slaked lime and was slowly rotated at a constant speed in grazing incidence with the flame. The size of the flame was kept as constant as possible by the use of a reducing valve and a gas regulator.

[3] Nichols and Crehore; Physical Review, *2*, p. 161; 1894.
[4] Nichols and Howes; Physical Review, *2*, *19*, p. 315; 1922.
[5] Nichols and Wilber; Physical Review, *2*, *17*, p. 453; 1921.
[6] Howes; Physical Review, *2*, *17*, p. 469; 1921.

Fig. 3 gives the distribution of brightness, thus obtained, in the visible spectrum of the air slaked lime. The luminescence was of an orange-yellow color characteristic of the broad band between .61μ and .53μ as indicated in the curve. The maximum lies near .56μ

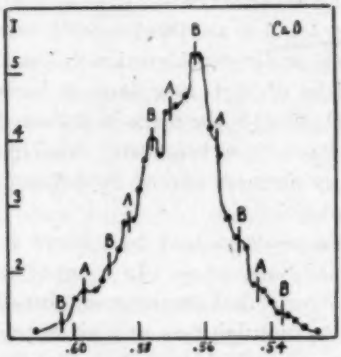


FIG. 3. *Submerged components in the spectrum of CaO when excited by the H flame.*

and the subsidiary crests and shoulders, marked by short vertical lines are not without a systematic arrangement. When the reciprocals of the wave lengths of the crests are studied they are found to lie in two series of a constant interval of 42 units designated as the *A* or *B* series. These wave lengths and reciprocals are given in Table 1 to-

TABLE 1. *Luminescence of lime*

Set *A* (Interval=42).				Set *B* (Interval=42).			
Band	Hydrogen Flame μ	Iron Spark μ	Frequency Unit $10^3/\mu$	Band	Hydrogen Flame μ	Iron Spark μ	Frequency Unit $10^3/\mu$
A_4	.5975	.5977	1673	B_4	.6045	.6046	1654
A_5	.5833	.5831	1715	B_5	.5894	.5896	1696
A_6	.5689	.5692	1757	B_6	.5755	.5754	1738
A_7	.5563	.5559	1799	B_7	.5617	.5618	1780
A_8	.5432	.5432	1841	B_8	.5488	.5488	1822
				B_9	.5365	.5365	1864

gether with the wave lengths previously obtained by excitation, with the iron spark, of natural calcite.[7]

[7]Nichols, Howes and Wilber; Physical Review, *2*, *12*, p. 364; 1918.

The positions of the bands *are the same under the two different modes of excitation* which indicates that when excitation by the hydrogen flame occurs, as has already repeatedly been shown to be the case for ordinary fluorescence, it is the activator which determines the spectral structure. Although the general form of the spectral envelope is quite different from that obtained by iron spark excitation, the partially resolved crests are in no way shifted by change in mode of excitation. The form of the envelope in Fig. 3 corresponds more nearly to that for the calcite under the iron spark excitation at 200°C than at 20°C. See Fig. 4 taken from the paper on calcites just cited. This is naturally so, since the hydrogen flame warmed the specimen to a temperature

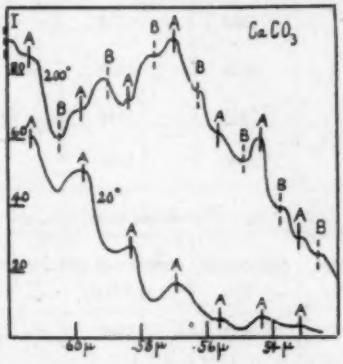


FIG. 4. *Submerged components in the spectrum of $CaCO_3$ when excited at 200°C and at 20°C by the iron spark. Compare with Fig. 3.*

of approximately 350°C. Temperature changes the relative intensities of the crests but the *A* and *B* series are *independent of both temperature and mode of excitation* for their frequencies.

Two phosphorescent sulphides containing bismuth as an activator which are known as Nos. 3 and 13 of Lenard and Klatt's list were also excited by the hydrogen flame in the course of the investigation made by Howes with results which show the identity of spectral structure as between photo-excitation, and flame excitation to pertain to these substances also. A comparison of the bands, which had been determined under excitation by the zinc spark some years before[8] with those found by Howes is given in Tables 2 and 3. Again we find the same sets of components making up the spectra whatever be the mode of excitation.

[8]Nichols; Am. Philos. Soc., *56*, p. 258; 1917.

TABLE 2. *Luminescence of calcium bismuth sulphide, No. 3*

Hydrogen Flame, μ	Zinc Spark μ	Frequency Unit $10^4/\mu$	Frequency Interval, Δ
.6365	.....	1575	
			39
.6208	.6200	1614	
			39
.6048	.6049	1653	
			39
.5912	.5910	1692	
			39
.5785	.5781	1731	
			39
.5650	.5650	1770	
			39
.5530	.5528	1809	
			39
.5415	.5411	1848	
			39
.5300	.5300	1887	

TABLE 3. *Luminescence of strontium bismuth sulphide, No. 13*

Hydrogen Flame, μ	Zinc Spark μ	Frequency Unit $10^4/\mu$	Frequency Interval Δ
.5565	.5562	1793	
			58
.5404	.....	1851	
			58
.5235	.5238	1909	
			58
.5080	.....	1967	
			58
.4938	.4938	2025	
			58
.4800	.4801	2083	
			58
.4668	.4670	2141	
			58
.4546	.4547	2199	

The interval for this sulphide as given in the table is quite consistent with the presence of Bismuth as an activator since within the errors of observation it is an exact multiple of the Tanaka[9] ratio 14.6 for series I of that element.

[9]Tanaka; J. O. S. A. & R. S. I., *8*, p. 314; 1924.

Fig. 5 is a diagram showing the submerged components of the band in the fluorescence spectrum of the phosphorescent sulphide known as Lenard and Klatt No. 13 when excited by the zinc spark (curve *Z*) and of the spectrum of the same sulphide under the action of the hydrogen flame (curve *H*).

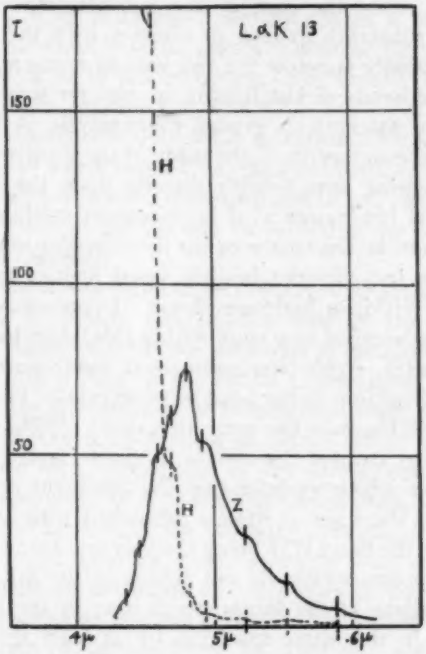


FIG. 5. *Submerged components in the spectrum of a phosphorescent sulphide when excited by a zinc spark (Z) or by the hydrogen flame (H).*

In the latter case only one side of an intense band having its crest in the violet or ultraviolet could be measured with the spectrophotometer. These two sets of determinations were made about four years apart using different instruments and there was no suspicion of any such relation between the spectral structure as was found to exist until the investigation was completed and the comparison made.

It will be noted from the figure that while as has been indicated in Table 3 the submerged components are identical as to position, different regions vary greatly in relative intensity under the two modes of excitation.

SPECTRAL STRUCTURE OF LUMINESCENT CALCIUM OXIDE IN A STATE OF INCANDESCENCE

The foregoing experiments establish the essential identity of substances excited to fluorescence by the hydrogen flame and by the usual methods such as ultraviolet light and cathode rays. They do not however fully cover the case of the luminescence of incandescent solids since a substance excited by contact with the active layer of the flame frequently is below the red heat in temperature. We have however at the hands of Dr. Boardman who for some time has been engaged in the attempt to extend the analysis of banded spectra with submerged components to the study of the spectra of incandescent solids, the following data bearing directly upon the question of the spectrum of the luminescence of incandescent calcium oxide.

Mr. Boardman in the course of his investigation photographed the spectrum of an incandescent bead of fused fluorite mounted upon a platinum wire within a hydrogen flame. Upon measurement of the negatives by the method now employed in this laboratory for the study of banded spectra, *eighty-three* submerged components assignable to the presence of calcium in the bead were revealed. These extend from the deep red .7215μ into the near ultraviolet .3839μ.

Most of these arrange themselves in six or more sets having the interval 42 from which we infer that the dominant activator is manganese. One of these sets is strictly coincident with Set *A* in Table 1 of this chapter, the band 1757 being the only one found in the cathodo- and H flame spectra which did not appear in the list of bands found in the photographs of the incandescent lime in the bead. This set is represented in the latter spectrum by at least three members of greater wave length, not picked up visually, and of at least ten towards the violet beyond the limits of the measurably visible group.

Set *B* of Table 1 appears at first glance not to conform to this analysis, there being but one band of the six listed in the table with which the spectrum of the incandescent oxide coincides. There are however four bands of this set in the red beyond the edge of the measurably visible group and at least four in the violet.

When in addition to the foregoing instances we recall that recent spectrophotometric studies of the visible radiation from incandescent oxides of titanium,[10] columbium[11] and neodymium[12] reveal a spectral

[10]Nichols; Physical Review, (2), *22*, p. 420; 1923.
[11]Nichols; Physical Review, (2), *25*, p. 376; 1925.
[12]Nichols; Proc. Nat. Acad. Sc., *11*, p. 47; 1925.

structure in all respects analogous to that here described the conclusion is warranted that the relation is wide spread if not universal.

OBSERVATIONS ON TRANSFORMATION SPECTRA

To many minds the observation of bands directly visible may seem to offer more convincing evidence upon the point here at issue than can be derived from submerged components of a broad banded or apparently continuous spectra. Such bands so far as luminescence at high temperatures is concerned are to be looked for chiefly where the rare earths are activators.

A significant instance is that of the transformation spectra described in a recent paper[13] where bands that could be identified as characteristic of the fluorescence of solids containing samarium, europium, terbium, etc. were observed in the spectra of incandescent beads containing traces of those elements.

When we add, as was found to be the fact, that such bands appeared only when the substance was passing through the temperature at which by previous measurements outbursts of luminescence are known to occur, the observation of the bands gains greatly added force in the argument for the oneness of fluorescence from the incandescent ranges down to the temperatures of liquid air or liquid hydrogen.

In the course of a description of low temperature investigations made in the laboratory of Kammerling-Onnes some twenty years ago Henry Becquerel introduces the following remarkable statement.[14]

"Si l'on examine avec un spectroscope la flamme d'un brûleur à gaz dans laquelle on introduit au bout d'un fil de platine un petit fragment de fluorine on observe un spectre de bandes analogue à ceux qu'emettent par phosphorescence les fluorines, soit dans le phosphoroscope, sous l'influence de la lumière, soit lorsqu'on les échauffe, soit lorsqu'on les excite par des rayons cathodiques.

"En juxtaposant dans le spectroscope l'un de ces derniers spectres avec le spectre de la flamme en question, on observe la coïncidence de plusieurs groupes de bandes et l'absence de certaines autres dans le spectre de la flamme."

Here is a statement of an observation which because of its unlooked for position in the literature, perhaps, has only at the time of writing come to our knowledge. With it our recent discovery of transformation spectra is in complete accord; affording a striking confirmation.

[13] Nichols; J. O. S. A. & R. S. I., *13*, p. 573, 1926.
[14] Henri Becquerel; C. R., *146*, p. 154, 1908.

In corroboration of both experiments we now have also photographs by Boardman of the spectra of fluorites (not yet published) in which are found these characteristic bands of the rare earths as hitherto known in the cathodo-spectra.

ACTIVATORS AT HIGH TEMPERATURES

Whether under conditions of incandescence activators dominate luminescence, the merest trace of copper or manganese or uranium, or of a rare earth controlling spectral structure, color, in great part, and brightness, as at ordinary temperatures, may perhaps be regarded as a no less important test of the identity of the two effects than is spectral structure itself. In the course of recent studies of incandescent solids[15] the luminescence was observed of two substances well suited to exhibit the effects of activators. These were:

(1) A sample of aluminum oxide with an admixture of chromium as in the making of synthetic rubies. (A finely phosphorescent preparation for which we are indebted to Mr. W. S. Andrews.)

(2) A crystal of fluorite showing after proper heating the narrow line-like bands in its cathodo-luminescence due to the presence of traces of rare earths. (This was one of the specimens then under spectrographic observation by Miss Frances G. Wick.)[16]

When incandescent these specimens showed the rather complicated outbursts of luminescence depicted in Figs. 6 (ruby) and 10 (fluorite) respectively. These were observed, through three color screens, successively, up to about 1500°C with the following results:

The Ruby. Inspection of Fig. 6 leads at once to the recognition of two distinct bands in the luminescent radiation. One of these occupies the part of the spectrum visible through the "blue" screen (equivalent wave length .45μ). This band attains very great relative intensity (at least 1540 times that of the black body radiation for some temperature well below 1000°C and probably near the threshold of incandescence. In other words it affords a marked example of the "blue glow." On the other hand the regions visible through the "red" (.65μ) and "green" (.52μ) screens are but little affected by the blue glow, the green very slightly, the red not perceptibly. Both of these regions however show marked luminescence just below 1000° and at about 1275°.

[15] Nichols and Howes; Physical Review, (2), *19*, p. 307; 1922.
[16] Frances G. Wick; Physical Review, (2), *24*, p. 272; 1924

To determine as far as may be possible by this method in how far these departures from black body radiation are attributes of Al_2O_3 which forms the solvent and what effect is to be assigned to the trace of chromium, the activator, these curves should be compared with those for Al_2O_3. For convenience of comparison the curves for each of the three colors (.45μ .52μ and .65μ) are plotted to the same scale separately in Figs. 7, 8 and 9 for Al_2O_3 and the ruby.

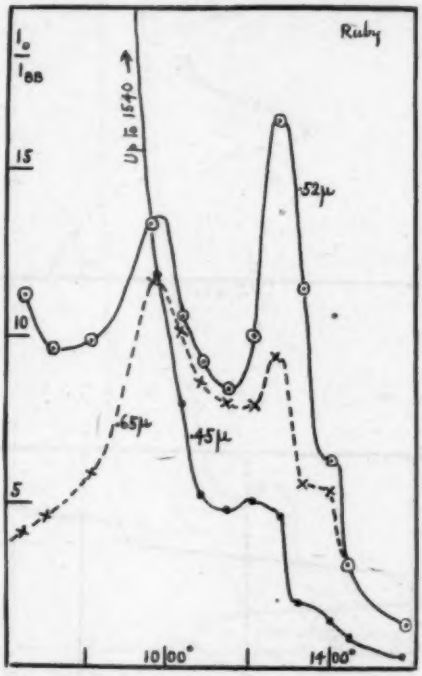


FIG. 6. *Luminescence of the incandescent ruby.*

In Fig. 7 (.52μ) we note that:

(1) For all temperatures below 1400° the brightness of luminescence is *greatly enhanced* by the presence of the activator while above 1400° the curves become practically identical.

(2) Of the two outbursts, which occur at transformation temperatures of Al_2O_3, i. e. just below 1000° and at 1400° the former is prominent in the curve for the ruby while the latter is largely suppressed, being represented only by a shoulder upon the curve.

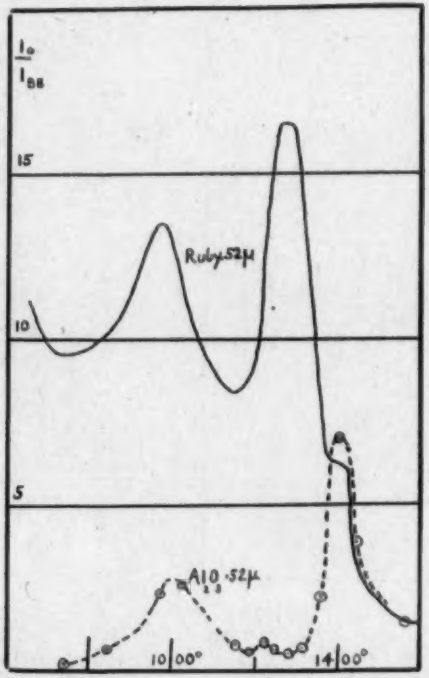


FIG. 7. *Luminescence of Al_2O_3 and the ruby as seen through the green screen (.52μ).*

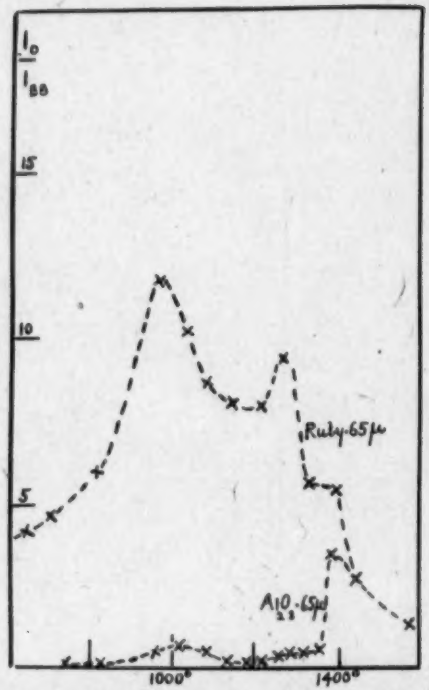


FIG. 8. *Enhancement of the luminescence of the ruby at .65μ; due to activation by chromium.*

(3) That the strongest manifestation of luminescence in this part of the spectrum occurs at about 1275°C at which temperature the radiation from Al_2O_3 is at its lowest or about .40 per cent of the corresponding black body radiation. It is understood that in all these diagrams the ordinates are the ratio of I_θ, the radiation from the oxide or other luminescent substance, to I_{BB} the cor-

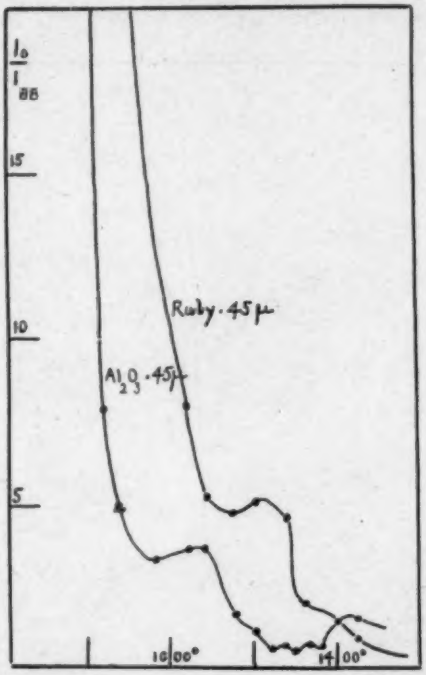


FIG. 9. *The blue-violet luminescence of Al_2O_3 and the ruby.*

responding black body radiation for the given temperature and wave length. Black body radiation would therefore be represented by a horizontal line of ordinate unity.

We have here actions which are highly characteristic of the effects of activators in ordinary fluorescence, i.e., *marked enhancement and a tendency to suppress luminescence due to other sources.*

In Fig. 8 we note even greater enhancement throughout the entire range of temperatures up to 1400°. In this part of the spectrum the radiation from pure Al_2O_3 never approaches black body intensity

until the outburst at 1400° is reached. Above that temperature both curves coalesce, as in Fig. 7, and approach black body intensity in the manner characteristic of the radiation of all these oxides after the range of temperatures at which luminescence occurs has been passed.

In the curve for Al_2O_3 in both Figs. 7 and 8 there may be noticed a slight suggestion of an accession of brightness above 1200° which perhaps corresponds to the crest of luminescence in the ruby and

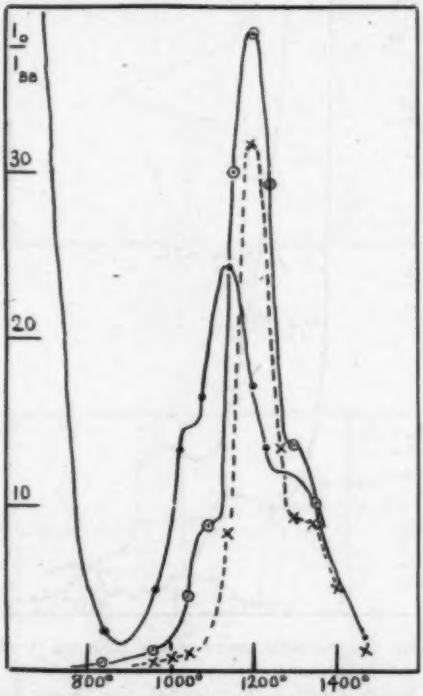


FIG. 10. *Luminescence tests of fluorite containing samarium.*

may be due to an exceedingly small amount of chromium, far below the optimum, present in the oxide. In Fig. 9 is a record of attempts to estimate brightness at various temperatures in the part of the visible spectrum where the greatest instability seems to prevail and almost inappreciable fluctuations of the exciting flame to produce wholly disproportionate variations in luminescence. The enchancement of

the ruby in the lower ranges is however evident;[17] also two crests of Al_2O_3 which are supplanted in the ruby by one of intermediate temperature.

The fluorite. The activator present in the specimen of fluorite whose luminescence is depicted in Fig. 10 was not definitely known at the time of our measurements. It would however be quite justifiable to name samarium as that activator after a comparison with the curves for samarium oxide in the paper on incandescent oxides just cited.[18]

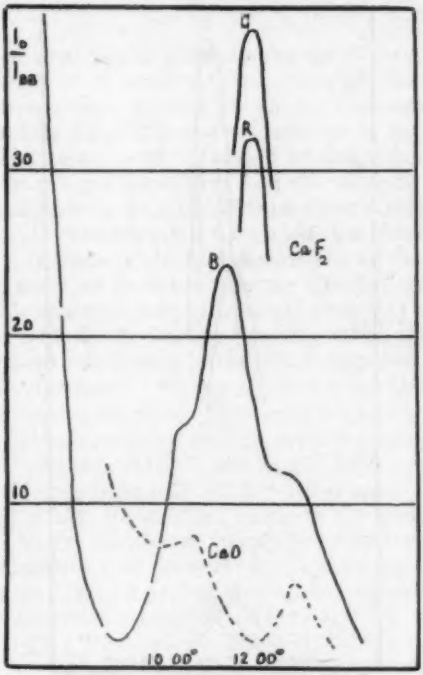


FIG. 11. *Luminescence of fluorite (.45μ), with curve for CaO and the red and green crests of fluorite (R and G)*

[17]Another striking instance of the effect of an activator was observed in the luminescence of columbium oxide. This sample was known to be impure. It did not agree as to melting point with the columbium oxide described in the writer's recent paper on this oxide. (Physical Review, *25*, p. 376. The blue glow of this material was so intense as to be measurable at 560°C at which temperature the value of $I:/I_{BB}$ for .45μ was 85200. (see Nichols and Howes; Physical Review, (*2*), *19*, p. 311.) At 655° the ratio was 2150 or nearly 40% greater than for the ruby depicted in Figs. 6 to 9. The nature of the activator is unfortunately unknown.

[18]Nichols and Howes, l. c., Phys. Rev., *19*, p. 310.

The crests in Fig. 10 do not correspond in temperature with the crests of CaO, which must be taken as the solvent rather than CaF_2 in the radiating surface layers of a crystal of fluorspar when heated to the temperatures in question in an oxy-hydrogen flame.

The shoulders of the curves however do represent the crests of the CaO curve as may be seen in Fig. 11 where that curve is dotted in for comparison. The *crests* are distinctly assignable to the element samarium, but greatly enhanced as appears in Fig. 12 where the three

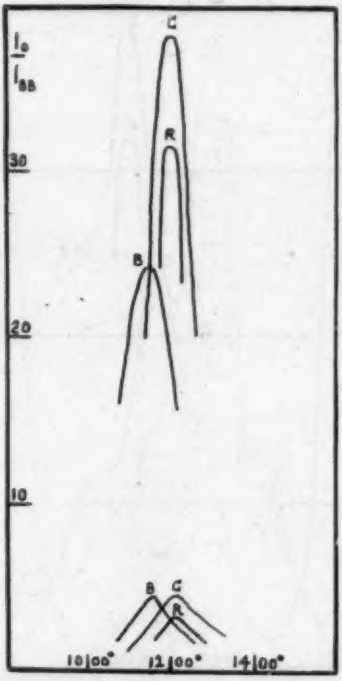


FIG. 12. *Fluorite (above) and samarium (below) showing enhancement.*

crests for fluorite are shown at the top of the diagram and the corresponding crests for samarium oxide drawn to scale at the bottom. The samarium crests are from a sample of that oxide *heated in bulk* instead of being greatly diluted in a solid solvent.

It has been the purpose in this paper to bring together the accumulating evidence connecting the luminescence of incandescent bodies with the fluorescence of solids at ordinary temperatures.

The writer holds that in view of the facts here presented the luminescence superposed upon the incandescence of the various solids is to be regarded simply as a *fluorescence* in all essentials identical with that commonly excited by light, cathode rays and other familiar agencies.

CORNELL UNIVERSITY,
ITHACA, NEW YORK,
JULY, 1926.

Generation of heat in the glow discharge.—Two plane-parallel electrodes are confined in a close-fitting glass cylinder of unspecified diameter; the upper one, serving as anode, contains an embedded thermometer, and its distance from the lower can be varied; the amount of heat it absorbs during a given period of time after inception of a glow discharge in the gas between it and the cathode (hydrogen contaminated with oxygen) is determined from observations with the thermometer. When the cathode fall is normal the fraction of the total heat generated which the anode receives diminishes as this latter is withdrawn into the negative glow towards the Crookes dark space; when the cathode fall is anomalous and the anode placed as near the cathode as is compatible with the existence of the discharge, the fraction of the total heat generated which goes to the anode increases very rapidly as the cathode fall is increased. The latter effect is ascribed by the author chiefly to the increasing efficiency of the positive ions in extracting electrons from the cathode, and by making several assumptions he calculates that the "emission-factor" for (e.g.) hydrogen ions ejecting electrons from Al rises from 0.17 for 400-volt ions to 2.2 for 2500-volt ions. The assumptions in question relate to the field in the cathode dark space and to the transfer of energy between ions and molecules, but are approximative and inexact; such problems, even when the geometry of the apparatus is as simple as in these experiments, evidently require a very elaborate statistical treatment.—[A. Günther-Schulze (Reichsanstalt); ZS. f. Phys. *37*, pp. 868–880; 1926].

KARL K. DARROW

Specific heat of ferromagnetic substances.—Previous measurements in this problem (of which there is a long bibliography in the article) are said to have been made exclusively by methods in which the integral specific heat over long temperature ranges from a low temperature T_0 to various high temperatures T_1, T_2, T_3 . . . . is measured, and then the mean specific heat between T_1 and T_2 (for instance) is determined from the difference between two such data—a process which requires great accuracy in the individual data to obtain even moderate accuracy in the differences, and exposes the material under

test to drastic changes of state. Sucksmith and Potter heat the specimen in a furnace to the desired temperature, and then communicate a measured small amount of heat to it by means of current in an embedded wire, measuring the slight rise of temperature which this produces (the Nernst-Eucken method). The curves for various samples of nickel and various samples of Heusler alloy (Cu 63%, Mn 25%, Al 12%) are of striking appearance, each having a sharp maximum at the critical temperatures; beyond this there is a rounded minimum and a gradual upturn. Measurements of magnetization made on the same samples during these experiments yield curves of which the differential curves have maxima lying at the same temperatures as the maxima of specific heat; each curve turns precipitously downward beyond its maximum. The authors conclude that the specific heat does not suffer an abrupt change at the critical temperature, and that agreement with the theory of Weiss is difficult or impossible to assert.—[W. Sucksmith and H. M. Potter; Proc. Roy. Soc., *A 112*, pp. 157–176; 1926].

KARL K. DARROW

Magnetism of molecules with odd or even numbers of electrons.—It seems natural, though by no means inevitable, to suppose that in molecules with an even number of electrons there is a greater likelihood of perfect compensation of the magnetic moments due to the several electron-orbits, than in molecules having an odd number of electrons. That is to say: molecules may plausibly be expected to be paramagnetic or diamagnetic according as they contain an odd or an even number of electrons. As is well known, comparatively few chemical compounds consist of molecules having an odd number of electrons, so that the possibilities of testing the idea are limited. The experiments of Williams upon solid oxides of the "odd-number" type show that out of the seven compounds CuO, $CuCl_2$, $CuBr_2$, BiO_2, MnO, CoO and AgO, all but the last are indeed paramagnetic; while the closely-related "even-number" compounds Cu_2O, CuCl, CuBr, Bi_2O_3 and Ag_2O_3 are diamagnetic, and so are the even-number compounds PbC, PbO_2, SnO and SnO_2. However, the even-number compounds Mn_2O_3 and Co_2O_3 conflict with the rule. (The compound CoO is ferromagnetic, at least in the sense that its permeability is very large and decreases with increasing field strength). The odd-number substances tested by Taylor were: ClO_2 in CCl_4 solution, thallium amalgam, sodium dissolved in ammonia and a certain organic free radical in benzene. Owing to the admixture of the presumptive odd-number molecules with those of other substances, the data require much adjustment, but lead to the conclusion that all of these substances are definitely paramagnetic:—[E. H. Williams (Illinois); Phys. Rev., *28*, pp. 167–173; 1926. N. W. Taylor (California); J. Am. Chem. Soc., *48*, pp. 854–859; 1926].

KARL K. DARROW

INSTRUMENT SECTION

ON THE WILSON CLOUD EXPANSION CHAMBER

By A. W. Simon[1] and D. H. Loughridge

The cloud expansion chamber of C. T. R. Wilson[2] is such an important instrument for both research and demonstration work that it is desirable to give a more complete description than that now available of its design and manipulation, and that is the object of the present paper.

The chamber which we describe below is the outgrowth of some three years of experimentation in this field and contains some new features which are distinct improvements over the chambers hitherto described.

In designing this instrument as well as in manipulating it, we have drawn fully on the information given by C. T. R. Wilson and others,[3] who have already laid the groundwork, and our efforts have been directed mainly at adding such improvements as will make the chamber more rugged, more convenient to use, and more certain in its operation.

Throughout the present work we are primarily concerned with x-ray and gamma ray technique, partly because experience has shown that this presents the most difficulties, and partly because alpha ray technique has already been adequately discussed by numerous other investigators.[4] On account of the intensity of ionization produced by alpha rays, the tracks generated by them are obtained and photographed with relative ease, in fact very simple means ordinarily suffice.[5] The intensity of ionization produced by x-rays and gamma rays, on the other hand, is comparatively faint, and rather accurate adjustment is required to produce good results.

THE EXPANSION CHAMBER

A practical form of expansion chamber is shown diagrammatically in Fig. 1, in which its dimensions have been carefully drawn to scale.

The entire apparatus is of brass except the roof 1 and the wall 2 of the expansion chamber itself, which are of glass. The roof is a disc

[1] National Research Fellow.

[2] Proc. Roy Soc., *87*, p. 277; 1912.

[3] An excellent summary of this work has recently been given by P. Auger, Thesis, University of Paris, 1926.

[4] A good discussion of alpha ray technique is given by I. Curie in Annales de Physique, p. 299, May-June, 1925; also by Meitner and Freitag, Zt. F. Phys., *37*, p. 481; 1926.

[5] C. T. Knipp and N. E. Sowers, this journal, *11*, p. 191; 1925.

of $\frac{3}{8}''$ plate glass, the wall a cylinder of glass $1\frac{1}{4}''$ high cut from a $10\frac{1}{2}''$ I.D. bell jar. The chamber therefore has an inner diameter of $10\frac{1}{2}''$ and so is much larger than any heretofore described. The plate glass roof is cemented to the upper face of a brass ring 5 with sealing wax, while the glass cylinder, the edges of which are carefully ground, is fitted into a groove in the lower face of this ring, and also cemented with sealing wax. This operation is best carried out in an electric

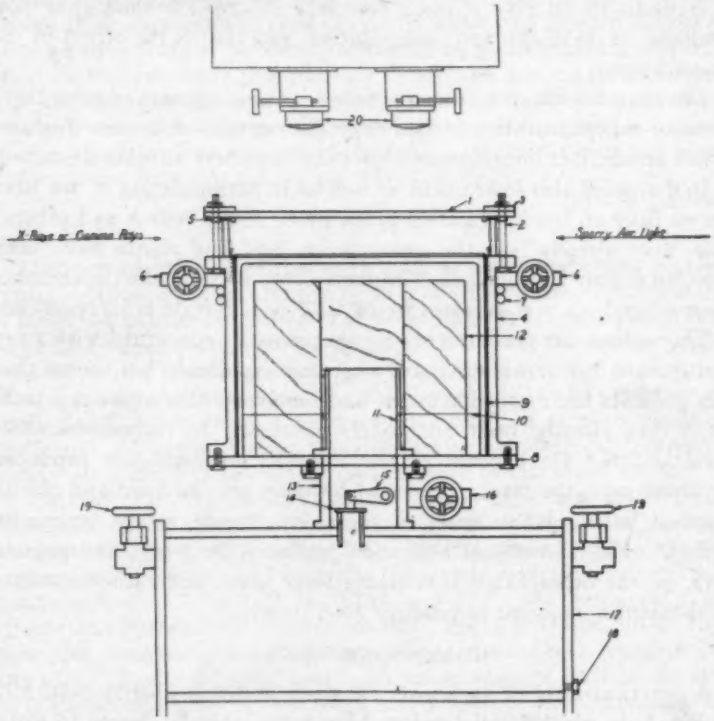


FIG. 1. *Diagram of expansion chamber.*

oven, in which the parts are heated slowly to about 125°C and are then allowed to cool. The brass ring performs the double function of strengthening the joint between the roof and the wall of the chamber and forming the electrode by means of which the electric field is applied to the chamber. The whole is then set on top of the expansion cylinder 4 and sealed airtight below by means of soft wax, (equal parts beeswax and rosin) which is applied with a small warmed pipette, the lip of the

expansion cylinder being subsequently warmed with a small blow torch to assure good contact everywhere. The glass chamber is held down by means of a second brass ring 3, which is secured to the expansion cylinder by means of a number of bolts. This enables the chamber to be put under pressure greater than atmospheric. Aside from the advantage in allowing gases under pressure to be studied, this is also extremely convenient in taking apart the chamber, since it is only necessary to apply compressed air through one of the needle valves 6 to lift the chamber and attached cylinder. A gasket is of course inserted between the second brass ring and the plate glass top to avoid strains. The expansion cylinder top also has a small ridge (not shown in the drawing) on the inner side to keep the soft wax from running over into the cylinder.

The expansion cylinder 4 itself (machined from a casting) is provided with a cooling pipe 7 through which tap water is run to keep water from condensing on the glass parts of the chamber, and also with two needle valves 6 for the admission of gases, adjustment of volume of gas in the chamber, washing the chamber with gas, etc. It is secured to the base plate 8 of the instrument by means of brass screws, a double gasket, consisting of a layer of $\frac{1}{8}''$ sheet rubber plus a layer of $\frac{1}{16}''$ rubber dam being inserted. In taking apart the chamber these screws are loosened and the expansion cylinder with the expansion chamber attached forced up with compressed air.

In smaller chambers a more convenient method is to take the glass expansion chamber off instead, by loosening the soft wax joint with a blow torch applied under the lip of the expansion cylinder. However, in larger instruments where the cylinder is massive, it is impossible to avoid heating up the whole apparatus, which is undesirable in cases where the piston itself is coated on the inside with wax or pitch to make it airtight. In a smaller chamber used by A. H. Compton and one of us,[6] where the lip of the expansion chamber was rather thin, it was possible to loosen the wax before the rest of the apparatus became heated, and by quickly cooling by means of cold water forced through the cooling pipe, the operation of sealing on or taking off the glass chamber could be accomplished without softening the wax on the piston itself or doing other damage.

The piston 9 itself (also machined from a casting) is provided with a ridge around the edge of its top face to hold in the gelatin coat. In

[6] A. H. Compton and A. W. Simon, Phys. Rev., *25*, p. 306; 1925; *26*, p. 289; 1925.

our case the piston itself weighs some thirty pounds, the whole being made massive for various reasons: to retain its shape; to act without vibration, to enable piston rings to be inserted, and reduce possibility of leaks (porosity of casting). This relatively large weight introduced a new difficulty, namely that the water level 10 in the cylinder was too high, a condition which resulted in splashing and even in water flowing over the top of the piston. However this whole difficulty was easily remedied by supporting the weight of the piston by means of a phosphor-bronze compression spring (not shown in the drawing) seated on the top of the central valve cylinder extension 11.

The space underneath the piston is filled up as completely as possible by means of a wooden ring 12, which is carefully treated with paraffin to make it watertight.

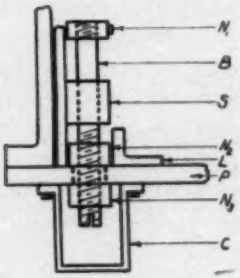


FIG. 2.

The vertical wall of the piston (Fig. 2) has soldered to it a sleeve S, which slides on a vertical bolt B. The latter carries at its upper end a nut N_1 (provided with a set screw) which limits the height of rise of the piston. The bolt at the same time keeps the piston from rotating. In order that the height of rise of the piston be adjustable from the outside, this bolt is threaded below through a square nut N_2, which is kept from turning by an L shaped stop L soldered to the base plate P. The bolt can be raised or lowered by means of a screw driver. To make the seal tight the bolt is further provided with a nut N_3 with a collar, over which is slipped a piece of tight fitting rubber tubing, which in turn fits into the aperture in the base plate of the apparatus. As an additional precaution against leaks, a brass cylinder C with a rubber gasket is fastened over the projecting part of the bolt.

The base plate is provided with two apertures which serve to admit the two tubes of a water gauge. One of these tubes ends flush with the floor of the chamber; the other extends vertically beyond the water

level. On the outside of the chamber these two tubes terminate in nipples to which two pieces of rubber vacuum tubing can be attached. The latter connect with the two ends of a vertical glass, in which the water level can be observed. To fill the chamber water is poured into the upper tube, which is slipped off the gauge and attached to a funnel for this purpose.

The water level itself need be only an inch or so above the floor of the cylinder. Too high a level may cause the water to splash during an expansion and must be avoided. The counterbalancing of the piston serves to keep the water level down. If the piston is not counterbalanced, the water level between the piston and cylinder wall may rise until it is near (or even above) the top of the piston. In this case splashing is hard to avoid.

Another cause of splashing, particularly if a stop is used to limit the height of rise of the piston, is a leak of air out of the upper chamber either around the piston gasket or through the piston itself. If the air is gradually sucked out of the chamber, the air in the latter will of course be at reduced pressure. Ordinarily, with no stop, the piston would rise higher on being let up until equilibrium is again restored. However with the stop this cannot take place and the water rises instead.

For this reason the leak of air out of the chamber must be avoided. This is done by choice of proper gasket on the one hand, and the avoiding of porosity in the piston on the other. The second point is taken care of covering the inside of the piston with soft wax.

In order to stop the splashing the piston might be fitted with piston rings, and the piston of our apparatus was originally equipped with grooves to take these rings. Subsequent experiments, however, showed that with the proper precautions (just discussed above) this splashing was avoided, and thus the need of piston rings was obviated.

The base plate 8 has a circular aperture which opens into the valve cylinder 13. Projecting upward from this aperture is the valve cylinder extension 11—a cylinder about 3½″ high, which prevents water from entering the valve cylinder. The valve cylinder itself contains the expansion valve, which on being opened produces the expansion.

The consistent action of this valve is important, since it affects the timing. Leaks also must be avoided since they cause the piston to creep. In order to insure that the valve seats properly, two small phosphor-bronze fingers (not shown in the figure) are introduced which

act as guides and keep the valve cap from tilting. The under side of the valve cap has a rubber gasket which is attached rigidly to it by means of a brass disc held by a screw.

The valve cap 14 is carried by one end of a lever 15, the other end of which is mounted on a shaft, which runs through the wall of the valve cylinder and is manipulated by means of an electromagnet from the outside.

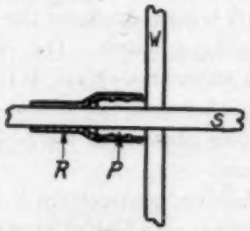


FIG. 3.

The manner of making an airtight seal between the shaft and wall of the cylinder is shown in Fig. 3 where *S* represents the shaft, *W* the wall of the cylinder, *P* a cylindrical projection, and *R* a piece of rubber tubing the two ends of which are sealed with shellac. This manner of making the seal is possible because the shaft need rotate only through a small angle. The outer end of the shaft carries a double lever arm, one end of which is attached to the plunger of an electromagnet, while the other is fastened to a spring which presses down the valve cap against the valve opening, and so assures a good seal.

The valve can be opened slightly by pressing down one end of the outer lever. This is convenient for producing slow expansions in clearing out the chamber and also in setting the piston. The piston is let up by admitting air through the needle valve 16, and let down by pressing lightly on the outside lever arm. If the piston is let down slowly by pressing lightly on the lever arm, the formation of a general cloud can be avoided.

The manipulation of the piston is then, after an expansion to let it all the way up by opening needle valve 16, to reduce the tendency of the air to leak around the piston gasket, and allow it to remain in this position until the time comes for another expansion. Then, by pressing slightly on the lever arm, the piston is allowed to fall slowly until it is somewhat below the correct setting, and now it is allowed to rise to the proper setting by opening the needle valve. With a little practice the whole operation can be carried out very rapidly.

Accessibility is an important requirement of the valve, since it may occasionally need a new gasket or some adjustment. For repairing the valve the expansion chamber plus the expansion cylinder is lifted off entirely, and also the valve cylinder extension.

The lower vacuum chamber 17 is provided with a drain plug 18 and also two valves 19, one of which leads to a mercury manometer and the other to an aspirator pump. As such we used four large brass filter pumps connected in parallel.

THE PENDULUM

The timing pendulum consists of the bob mounted on the lower end of a rod, the upper end of which is attached to a horizontal shaft. This shaft, which is mounted in well oiled bearings to eliminate friction, carries four commutators, each of which is simply a fiber disc with a metal inset on its periphery. Four stationary metal phosphor-bronze brushes slide one on each of the peripheries of these discs and establish the contact with the metallic segments. Three of the commutators have a single segment each, the fourth (that controlling the electric field) has a double segment so arranged that when the pendulum is drawn back the voltage is applied to the ring electrode of the expansion chamber but so that just before the rays enter the voltage is cut off and the ring electrode grounded.

Each of the fiber discs is fixed to a short brass cylinder, (collar) which slips over the shaft of the pendulum, and can be rotated with reference to the shaft so as to vary the point at which the contact takes place between the metallic sector and stationary tongue. The brass collar is of course provided with a set screw. It is also very convenient to provide the fiber disc with a circular scale and the pendulum shaft with a pointer (index) which plays over this scale, so that the angle through which the disc has been displaced with reference to some arbitrary zero line on the shaft can be read off. This is extremely convenient for adjusting the timing.

The pendulum is released by means of a spring catch, which can always be set at the same point and does not impart any momentum to the pendulum. The pendulum is caught at the end of its swing by a second catch, which is arranged to trip a master switch, which then cuts off the current through the electromagnets, and also the current to the high tension condenser if exploded wires are used.

The pendulum, exclusive of the bob, the commutators and the catches, can be constructed almost entirely of laboratory clamps, rods,

and tripods. The bearings can be two clamps, with round holes, the shaft and vertical rod can be laboratory rods, etc.

When exploded wires are used the pendulum is prolonged at its upper end by means of an ebonite rod carrying two spark balls, which pass between two fixed (but adjustable along the arc of swing) spark balls.

If the x-ray tube is to be run continuously, then the rays can be admitted by means of a moving slit. For this purpose a lead screen (a portion or whole of a lead disc) with a small aperture is mounted on the shaft of the pendulum. A fixed lead screen with a second aperture is placed parallel to the first and so that at one place the two apertures come in line. For convenience in adjustment it is well to choose this point so that the two apertures are in line when the pendulum is at rest i.e. at the bottom of its swing. The duration of the admission of the rays can be varied by varying the angular width of these two apertures.

When gamma rays are used, a second auxiliary pendulum is used. The radium is attached to the bob of this auxiliary pendulum, which is actuated by the shaft of the main pendulum through a rod (of small diameter) which forms a prolongation of the shaft of the main pendulum. The whole arrangement is enclosed by means of a lead block, 8″ on a side, built up of sheets of $\frac{1}{8}$″ lead bolted together.

TECHNIQUE

A discussion of the technique of the Wilson cloud expansion chamber centers around four important points: (1) The production of an accurate expansion ratio (2) An accurate timing of the events (3) A clean chamber (4) Elimination of disturbing air currents.

1. *The Expansion Ratio.* An accurate duplication of the expansion ratio is absolutely essential if consistent results are to be obtained. The exact ratio varies a little with temperature, speed of descent of the piston, nature and age of the gas in the chamber, etc., so that it is best determined by a few trials before each run.

We have found that the expansion ratio must be adjusted with great accuracy, a variation of one tenth of a millimeter (where the total drop of the piston is 9 mm) in the setting of the piston producing a considerable variation in the clearness and sharpness of the tracks. Since the absolute ratio is not of great interest, it is convenient merely to duplicate accurately the setting of the piston. This can be done by means of a short focus telescope with a micrometer scale in the eyepiece, the telescope being rigidly attached to the

chamber. The telescope is focused on some convenient scratch on the piston, and the correct setting found by a few trials. For absolute determinations a cathetometer is employed.

For an accurate adjustment of the height of the piston, the pressure below it is regulated by admitting air through a needle valve. The latter must be capable of very fine adjustment and must also seal perfectly, since a very small leak would enable the piston to "creep" past the correct setting. We have found ordinary brass needle valves entirely satisfactory for ease and rapidity of adjustment, and also for air tightness.

In order that the ratio, once accurately determined, shall stay constant to a high degree of accuracy, other factors must also be maintained constant, and these we shall next consider.

In the first place the speed of descent of the piston must be kept fairly constant. This is effected by adjusting the pressure in the vacuum chamber approximately to the same value, a mercury manometer being attached to it for this purpose. In addition the expansion valve mechanism must function consistently. Aside from the proper design of the valve, this means that in our case, where an electromagnet is used, the current through the latter also must be kept fairly constant.

It is evident that any form of leak will interfere with the accurate setting of the piston and therefore the consistent operation of the chamber. In fact leaks account for most of the troubles encountered in the operation of the chamber so that it is worthwhile to consider them in detail.

Leaks may be classified as follows: those between the chamber and the air outside; those between the chamber and the space below the piston; and those between the space below the piston and the air outside.

Unless the gas in the chamber is at a pressure greater than atmospheric, the first kind of leak mentioned above takes place only from the air outside into the chamber. Such a leak is detrimental for two reasons: first, it changes the mass of gas in the chamber and, second, it changes the nature of the gas in the chamber. The latter point has to do with the cleanliness of the gas and will be discussed separately under that head. The existence of the leak in question is easily detected by the fact that the equilibrium height of the piston i.e. the height to which it rises when the space below it is opened to the air, continually decreases.

A leak from the space under the piston into the chamber may take place either through the piston or around the piston gasket. The existence of such a leak is manifested by the equilibrium height continually increasing. To avoid a leak through the piston the latter is coated on the inside with a layer of soft wax, or other material not attacked by water. If the seal between the piston and piston gasket is imperfect, then the pressure of the air in the chamber drives the water (on which we rely for the air seal) around the gasket into the space under the piston and finally some of the air leaks directly into the space beneath the piston.

Since, however, this process requires appreciable time it can usually be forstalled by letting the piston up again immediately after an expansion, and our apparatus has always been operated in this way.

For the gaskets various kinds of rubber have been tried. The gasket, in addition to making the seal, must also absorb the shock of the piston and must do this smoothly. After trying various kinds of rubber we have found that a layer, $\frac{1}{8}''$ thick, of grey sheet rubber (known commercially as staple sheet packing) plus a layer of $\frac{1}{16}''$ pure rubber dam is most effective. The first takes up the shock, and the second makes the seal.

The third kind of leak, namely that into or out of the space below the piston will only affect the height to which the piston is set. A leak into the chamber usually occurs through the needle valve and is manifested by the piston creeping upward after it has been set, until it has reached the equilibrium setting. A leak of this kind is usually easily remedied. A leak into the vacuum chamber is usually due to an imperfect seal of the gasket on the expansion valve, and is manifested by the piston creeping downward after setting. This leak also is easily remedied by proper adjustment of the expansion valve and its gasket. Unless the latter is rigidly attached to the valve cap, the rubber of the gasket may be held down on the valve opening due to the suction, for this reason it is best to attach the gasket to the cap by means of a disc or a ring, or both, so that the rubber will be drawn up with the cap. In some cases we have fastened the rubber gasket on with sealing wax and a metal disc.

The speed of descent of the piston is controlled by the size of the opening of the expansion valve, the height to which the cap is lifted, the speed of operation of the valve, ratio of volume of vacuum and piston chamber, ratio of pressures, etc. The descent should not be too violent.

Another requirement under the head of the attainment of an accurate expansion ratio is that the piston do not rotate as otherwise the scratch observed through the telescope will pass out of the field of view. Also in order to obviate setting the piston for each expansion by means of the needle valve and telescope, it is desirable to provide a second adjustable stop which, once set at the proper point, automatically allows the piston to rise to this point. We have introduced a stop which performs both of these functions, but so far this has not been entirely practical as far as the second one is concerned due to the fact that is difficult to manipulate and that it does not stay in close enough adjustment. We have found it much easier to set the piston each time with the needle valve and telescope. From the point of view of automatic devices, however, the perfection of such a stop is extremely desirable.

2. *Cleanliness of the Gas in the Chamber.* By a "clean" chamber we shall define one which contains, at the instant of expansion, no condensation nuclei except those it is desired to observe.

The undesirable nuclei can be divided into two classes (1) those electrical in nature (2) and those not electrical in nature.

The first class, which consists of ions left over from previous expansions or produced by stray radiation, radioactive contamination, etc., is easily removed by electrical precipitation. It is only necessary to apply a difference of potential between the roof and floor of the chamber. For this purpose an electrode in the form of a flat ring is placed on the roof of the expansion chamber and a difference of potential applied between this ring and the base of the expansion chamber. The magnitude of this potential will vary with the intensity of the stray ionization and the interval between expansions. If an alpha ray source is being examined and expansions made in rapid succession a potential difference of 200 volts may be necessary to clear out the chamber; if, on the other hand, x-rays or gamma rays are being examined, a few volts usually suffice. This field of course must be cut off just before the rays to be observed are admitted to the chamber, and this requires not only that the source of emf. be disconnected from the chamber, but that the ring electrode actually be grounded to the chamber.

When high electric fields are used and a bare plate glass roof (i.e. if no gelatin coat is used) the sharpness and clearness of the tracks is extremely sensitive to changes in electric field. Too low an electric

field is not sufficient to remove the stray ions, while too large an electric field causes the tracks to become fuzzy. The explanation of the latter phenomenon is no doubt that charge creeps out on the glass roof of the chamber and is not discharged completely (due to the high resistance of the surface of the glass) before the new rays are admitted. With a clear glass top and x-rays or beta rays as the source we found as did C. T. R. Wilson, that a voltage of about 4 volts per cm is sufficient.

With a well conducting gelatin coat on the roof of the chamber much greater potentials can be applied without appreciable effect. The ideal condition would be to have a transparent conducting layer for the roof of the chamber, and perhaps this is an argument for retaining the gelatin layer on the roof of the chamber.

However, large fields are not vital, for most ordinary purposes the bare glass top and inserted ring electrode will suffice. The absence of the electric field is quickly manifested by the appearance of bulky "cumulus" clouds in the chamber. The correct adjustment of the electric field is absolutely essential to sharp tracks.

The second class of undesirable nuclei, namely those which are uncharged, are not so easily dealt with. No doubt a large percentage of this second kind is made up of dust particles. C. T. R. Wilson has shown that water condenses on the dust particles before it condenses on the electrical nuclei, and therefore it is desirable to remove this dust. It is always found that when fresh air is admitted large numbers of stray ions, which manifest themselves by clouds superposed on the tracks after an expansion, are present. The correct expansion ratio also appears to be extremely critical under these conditions. This effect diminishes only with time, although certain factors seem to hasten the process.

After the air has been aged, the remaining nuclei can usually be precipitated by a few slow expansions before each run.

If these disturbances are due to dust any agency which will remove the dust should hasten the process of "cleaning out." When the chamber is first sealed up it is impossible to exclude dust; however, if air must subsequently be admitted, it could be treated by filtration or other means of cleaning it. Filtering through cotton and glass wool was tried by us with partial success.

We have found that a very moist gelatin coat on the piston top is extremely effective in cleaning out the chamber, no doubt due to its

property of absorbing the dust which falls on it. In one instance where the gelatin coat on the piston top had been heated until it became fluid and the chamber was then immediately sealed up, very beautiful clear tracks were obtained within a few hours after sealing up the chamber.

Experiments made with a bare piston top and with the top covered with paraffin or beeswax, were entirely unsuccessful.

When the correct expansion ratio is exceeded, that is when an overexpansion is produced, the nuclei formed seem to persist for some time, and can only be removed by a number of slow expansions. It is therefore best to avoid overexpansions, in finding the correct expansion ratio it is best to approach it from below.

3. *Timing of the Events.* The third essential in the operation of the chamber is the accurate timing of the events, namely: the collapse of the electric field, the expansion, the admission of the rays, the photographic exposure.

Of these four intervals the one between completion of expansion and admission of the rays requires accurate adjustment. After the drop pattern has been found, it persists for an appreciable time before gravitation and air currents interfere, so that the timing of the photographic exposure is not critical. The electric field should be reduced to zero just before the rays are admitted, if charges have crept out on the glass top of the chamber, the ring electrode should be grounded soon enough to permit this charge to leak off.

For the purpose of the timing we have used a single pendulum which times the various events through electrical contacts of a multiple commutator mounted on its shaft. This commutator (1) cuts off the voltage from the ring electrode and then grounds the latter to the base of the expansion chamber (2) produces the expansion by sending current through an electromagnet which opens the expansion valve (3) admits the rays and (4) makes the exposure.

The admission of the rays can be carried out in various ways depending in the nature of the source i.e. whether it is an x-ray tube or a quantity of radium.

If x-rays are used and flashes are satisfactory for the purpose in hand, then a pulse can be sent to the primary of the transformer through the commutator. If quantitative results are desired i.e. if the voltage applied is to be accurately known or if direct current is used, then it is best to keep the x-ray tube running continuously

and admit the rays through a slit in a lead screen fastened directly to the pendulum, as was done for example in the experiments of A. H. Compton and one of us.[6]

If gamma rays are used a moving lead screen would be rather cumbersome. However in this case the source itself can be moved past a slit in the manner already described. For this purpose the radium is mounted on the bob of a small auxiliary pendulum, which is rigidly attached to the shaft of the main pendulum and swings in sychronism with it. The auxiliary pendulum, which need be only a few inches long, can easily be placed inside a lead block to shield the chamber from the gamma rays.

The photographic exposure can be carried out in two different ways, depending on whether an arc light is used for illumination or an exploded wire. If an arc light is used, the camera may be actuated by an additional electromagnet operated by the commutator. If an exploded wire is used as the source of illumination, the wire is fired by means of a spark gap, one element of which is fastened to the pendulum. In the experiments of A. H. Compton and one of us, the pendulum carried an ebonite rod above the shaft, and on the upper end of this rod were mounted two spark balls which passed between a pair of fixed spark balls and so made the circuit between the high potential coating of a condenser and the tungsten wire to be exploded.

4. *Vortex Motion.* This last point needs only brief discussion. It is clear that any air currents (vortex motion) will distort the drop pattern produced and must be avoided. At the instant the piston moves down the air rushes from the volume above into the space vacated by the piston and if the cylinder walls are straight and flush with the piston walls, if no obstacles intervene, and if the piston moves down without any vibration, the air will be displaced parallel in the direction of motion of the piston and come to rest without any disturbance. If however, the cylinder walls are recessed, or if side tubes are provided, then the air will rush out of these spaces, and produce a violet turbulent motion, which interferes seriously with the tracks. The chamber walls should therefore be nearly a prolongation of the cylinder walls, and all side tubes should be avoided. If a side tube is introduced it should not extend into the chamber, and, furthermore, be provided with a stopper which comes flush with the inner wall of the chamber. Obstacles inside the chamber should

also be avoided, since these have a tendency to deflect the air and set up turbulent motions.

If obstacles are introduced they should have walls which are parallel to the direction of motion of the piston and extend the full height of the chamber. If care is taken, although it may not be possible to eliminate the vortex motion entirely, it can at least be so reduced that it does not reach the tracks until after they have been photographed.

ILLUMINATION AND PHOTOGRAPHY

For visual work a single 500-watt steroptican Mazda lamp can be used to illuminate the tracks. Remarkable differences in intensity of the tracks can be noted depending on the angle at which the tracks are viewed. The tracks appear brightest when the observer looks in the direction of the source of light but at a small angle to the direction of the incident beam.

A small flash light lamp is also required to illuminate the scratch on the piston used to set on.

For photographic work a very intense source is required, particularly if the photographs are taken in a direction perpendicular to the illuminating beam. As such a powerful arc light (Sperry arc) or exploded wires can be used. Each of these methods has its advantage and disadvantages.

In either case the amount of apparatus required is about the same. In the case of the arc (unless direct current is available) a motor generator set capable of delivering 150 amperes and a Sperry arc mechanism are required. In the case of the exploded wires a source of high tension direct current, a transformer and a kenotron rectifier or a large static machine, and a large high voltage condenser about .1 mf at 50 kv are required.

However the method of exploded wires has the advantage that large amounts of apparatus need not be in close proximity to the chamber—a condition which practically forces the adoption of this method when the chamber must be carefully shielded, i.e. enclosed in a lead box, as the wires and their holders do not require much room and the wall of the box need be pierced only with a hole large enough to admit a high tension bushing, which can itself be shielded with lead, so that for all practical purposes the chamber can be completely shielded. With the arc, on the other hand, the wall must be pierced with a hole large enough to admit the beam, with very little possibility of adequate shielding.

Another important advantage of the method of exploded wires is that it introduces no heating of the chamber with its attendant disturbances. This is also an advantage over the mercury spark method, which requires a heating of the quartz tube containing the mercury. Here again if the apparatus must be shielded, the exploded wire method is almost imperative.

The effective quantity of light available from the two sources is about the same. The wires have an advantage that they can be placed close to the chamber and are practically a line source, a fact which permits a very efficient use of the light, since with a cylindrical lens or reflector exactly the geometrical beam required for the purpose can be attained. With an arc, on the other hand, a large part of the light must needs go astray, since it is difficult to compress the light emanating from the crater into a rectangular beam of large width but small height such as is required for the purpose. However, the arc light has the advantage that the time of exposure can be lengthened, so that the total quantity of light received by the photographic plate is increased on account of the greater time factor. The drops persist for almost a second in their original positions, so that a rather long photographic exposure can be made, an instantaneous photograph not being necessary.

The timing of the exposure is of course more exact in the case of the exploded wires, although this is not of great importance. There can also be an almost exact duplication of conditions, since the dimensions of the wire, its position, and the voltage applied can be duplicated very exactly. An arc will require more or less continuous adjustment.

One difficulty encountered in the use of the exploded wire method is the quick replacement of the wire. This was solved very neatly by A. H. Compton by means of the following device (hitherto unpublished).

The holder for the wire is a slide, which works in a stationary grooved holder. On the slide are two uprights of sheet copper, which extend downward into the groove, where they make contact with two metal inserts. These are connected, one, through the spark gap, to the high tension condenser and the other to ground. One of these uprights carries a connector with a thumb screw, while the other is shaped so as to form a hook. The wire to be exploded (a tungsten wire 6″ long and 3 mils in diameter) is spotwelded to a straight shank at one end, and to a looped wire (a Gem paper clip) at the other.

To replace a wire the slide is withdrawn from the holder, the loop is slipped over the hook and the shank drawn through the connector until the wire is taut then the thumb screw turned down, and finally the slide replaced in the holder. The whole operation can be carried out very quickly. A supply of tungsten wires is of course prepared beforehand.

If it is desirable to illuminate from two sides of the chamber, a wire can be placed on each side and the two connected in series.

If an arc is used it should be provided with a shutter so that the light can be admitted only at the instant it is needed. Unless this is done extraneous clouds are formed. Whether these are due to local heating or to ionization or to both, has not been investigated. This difficulty is entirely avoided with exploded wires. It is however necessary in the latter case to surround the apparatus with a light tight box or to darken the room when an exposure is to be made. The camera is then merely set for time exposure, the exposure being made when the spark balls in the pendulum pass through the gap. In the case an arc is used, the camera shutter is operated by a second electromagnet timed by one of the commutators on the pendulum.

It is desirable also to keep the light off of the bottom of the chamber. This can be done by rendering it parallel with a cylindrical lens, and also by admitting it through parallel slits (rectangular apertures).

A convenient form of high tension condenser can be constructed of milk bottles. An ordinary milk bottle will withstand, for periods of the order of ten minutes, a direct current voltage of some 70 000 volts, although if 30 000 volts is applied for an hour, the same bottle is apt to break down. Now for the purpose of photographing the tracks in the expansion chamber, the voltage need be applied only for a few minutes so that the milk bottles are entirely satisfactory. Also a milk bottle condenser has an enormous advantage, which overshadows that of any other type, namely that if it breaks down only a small part (1% if 100 bottles are used) of the whole condenser becomes ineffective, and that can be repaired in a few minutes by simply replacing the bottle. A run of observations need never be long interrupted due to a breakdown in the condenser. In the experiments of A. H. Compton and one of us, where such a condenser was used, the milk bottles contained salt water on the inside and were covered with tinfoil on the outside (although saltwater can be used both in and out) and the bottles, some 180 in number, were set in a large galvanized

iron vat on a shelf above the apparatus. The bottles were charged with kenotron rectifier and transformer.

For automatic devices the arc is no doubt the most convenient, although it would be possible to design a mechanism to use the exploded wires. For the latter purpose the wire could be inserted into a properly designed cartridge and a mechanism provided for automatically removing and replacing these cartridges after each exposure.

With either type of illumination very fast plates are necessary. For this purpose Eastman "Speedway" plates have been found satisfactory, although their grain is quite coarse. We have used specially matched Tessar lenses (20 Fig. 1), using their full aperture f 4.5. These provided sufficient depth of focus to cover the whole chamber depth. An 8×10 Graphlex focal plane shutter simultaneously exposed two plates.

MANIPULATION AND ADJUSTMENT

An important detail in the manipulation of the chamber is the preparation of the gelatin coats. The function of the opaque coat on the floor of the chamber is to catch the dust, provide a black background, and presumably also to hold some moisture. We have used the following mixture; 50 cc of hot water, 5 grams of gelatin, 5 cc of a 5% solution of phenol in alcohol, 0.5 grams of lampblack, 0.2 grams of copper sulphate or boric acid. The mixture is poured on while still warm enough to be fluid. It is poured through cheesecloth, which removes lumps, bubbles, etc. In fact the use of the cheesecloth assures an absolutely smooth, clean, and glassy coat. The piston top should be warmed beforehand.

The transparent coat for the roof of the chamber is prepared by dissolving 5 grams of gelatin in 100 cc of hot water and adding 5 cc of a 5% solution of phenol. This mixture is also poured through cheesecloth, the chamber (turned bottom side up) being previously carefully leveled with a spirit level. It is extremely important to have the surface on which the gelatin is poured *dry*, to assure good contact everywhere. The coat is made only a few millimeters thick, and allowed to dry over calcium chloride, a small lamp being used to promote circulation of the air.

The apparatus being assembled with the gelatin coats in place, water is poured in through one of the tubes leading to the glass gauge, and then the apparatus is ready for adjustment.

Unless measurements are to be carried out at reduced or increased pressure, the mass of gas in the chamber is adjusted so that on an

expansion the ratio of volumes will be somewhat in excess of 1.3. This is done by opening one of the needle valves and forcing up the piston until it is at the proper height, and then closing the valve. (It may now be necessary to wait for a few hours until the chamber has become clean enough to carry out the next step.)

Next a few slow expansions are made to precipitate the dust. If this test shows that the chamber is fairly clean, the final adjustment can be made. This consists in finding the correct setting of the piston and of the commutator which controls the expansion. For this purpose it is best to use a fairly strong beam of x-rays or gamma rays.

Beginning with settings below that required to give a ratio of volumes of 1.3 and with the commutator set so that the rays enter after the expansion, the piston is gradually set higher and higher until the setting is found at which fuzzy tracks begin to appear. This setting is just short of that which produces a general cloud. If a general cloud has been produced, a number of slow expansions are made to precipitate the nuclei formed. When fuzzy tracks begin to appear, (it may be necessary to vary the commutator setting somewhat) than the fine adjustment is made. This consists in varying both the piston setting and the expansion commutator setting until the best combination is found for sharp tracks. As a final adjustment it may be necessary to vary the field somewhat, especially if no gelatin is used on the roof of the chamber. It is also necessary finally to decrease the intensity of the x-ray or gamma ray beam until that giving the desired number of tracks is attained.

If extraneous clouds continue to appear, either the air in the chamber has not aged sufficiently or the field is not working. The presence or absence of the electric field and also changes in its value, produce great differences in the clearness and sharpness of the tracks.

In the foregoing it is of course assumed that no leaks occur. Leaks produce erratic performance of the chamber. The detection and remedy for the leaks have already been discussed above. After the tracks have been obtained visually, the timing of the photographic apparatus is adjusted, and the apparatus is ready for use.

In conclusion we wish to thank Professors A. H. Compton and R. A. Millikan for their inspiration and guidance, Mr. J. Pearson for contributing a great deal to the design of the chamber, and Mr. B. Merkle for the mechanical excellence of the finished chamber.

NORMAN BRIDGE LABORATORY,
CALIFORNIA INSTITUTE OF TECHNOLOGY,
PASADENA, CALIFORNIA.

Distribution-in-angle of electrons set into motion by polarized X-rays.—By the Wilson expansion-method, the paths of electrons set into motion in air by polarized x-rays are rendered visible and photographed with a camera pointed towards the oncoming x-ray beam, so that the angle θ, between the electric vector of the beam and the projection of the electron path upon the plane of the wave front, can be measured directly. On making a statistical study of an unspecified number of electron trails produced in air by radiation of wave length <0.2A, all of which must have been trails of recoil electrons which had participated in x-ray scattering, Kirchner found that the distribution-in-angle is a smoothly-varying function of the form $const \times (1+\sin^2\theta)$, having its maxima in the directions perpendicular to the electric vector. This implies that the most probable direction of the scattered x-rays is normal to the direction of the electric vector, which agrees with the inference from the classical interpretation of scattering. As for the electrons due to x-rays of three times as great a wave length, which are "photoelectrons" or electrons extracted from atoms through absorption of quanta, the most probable values of θ are 0° and 180°, as F. W. Bubb previously found. The maxima in this distribution-in-angle curve are much sharper than those in the other, and the minima at 90° and 270° seem to be nearly zero. There is no indication that the distribution-in-angle depends on the frequency of the exciting ray, rather the contrary.—[F. Kirchner (Munich); Phys. ZS., *27*, pp. 385–388; 1926.]

KARL K. DARROW

The Solidification of Helium.—On June 25, liquid helium was solidified in the Cryogenic Laboratory of the University of Leyden, by compression in a brass tube cooled with liquid helium. At a temperature of 3°.2 K and a pressure of 86 atmospheres, and, also, at 2°.2 K and 50 atmospheres pressure the liquid solidified. On July 1, the experiment was repeated and earlier observations confirmed. On this date the liquid was solidified at 4°.2 K and 150 atmospheres pressure, and at 1°.1 K and 26 atmospheres. The extension of the freezing point curve determined by these observations does not intersect the boiling point curve, for which reason it appears helium does not have a triple point.

Helium solidified in a glass tube was observed to be a homogeneous transparent mass. A surface of separation between solid and liquid was not visible. That solidification had taken place was proven by the fact that the stirrer was arrested and by the fact that in one case in which only a part of the liquid solidified, the solid could be hammered with the stirrer which turned freely in the liquid above. The index of refraction of solid helium can, therefore, be only slightly different from that of the liquid.—[W. H. Keesom; Comptes Rendus, *183*, pp. 26–27; 1926.]

F.G. BRICKWEDDE.

INVESTIGATION OF THE FORM OF THE SO-CALLED PUNKTAL LENS

By James P. C. Southall

INTRODUCTION

Modern spectacle glasses, as is well known, are almost invariably meniscus in shape with the concave surface turned towards the eye. In order that the definition obtained in looking through the glass obliquely shall be practically just as good as when the line of fixation coincides with the axis of the lens, the curvatures of the two surfaces of the lens should be adapted as far as possible to get rid of the natural astigmatism that is characteristic of a narrow bundle of refracted rays whose chief ray is inclined to the axis at an angle which, so far from being inconsiderable, may amount to as much as 28° or 30° on either side of the axis, corresponding to the angular amplitude of the field of fixation of the mobile eye. The center of the virtual stop that determines the chief ray of the bundle in such a case as this is not, as might be supposed at first thought, the center of the entrance-pupil of the eye, but the center of rotation of the eye or the pivot of the eyeball, which is likewise the point of intersection of all the lines of fixation. This point, approximately on the optical axis of the eye and not far from the geometrical center of the eyeball, is about 13 mm from the vertex of the anterior surface of the cornea. In order to allow perfect freedom of movement of the eyeball and eyelids, the clearance between the glass and the eye should be perhaps a little more than a centimeter; accordingly, the average distance of the center of rotation of the eye from the vertex of the nearer surface of the glass, as measured along the axis of the lens, may be taken as 25 mm. The chief ray of a narrow bundle of rays emanating originally from a point of a far distant object is therefore that ray which after traversing the lens crosses the optical axis at this specified point where the center of rotation of the eye is assumed to be when the lens is being actually used as a correction-glass in a case of ametropia. Consequently, when the lens is calculated with reference to this point so as to be free from the so-called astigmatism of oblique incidence, rays proceeding from any point of a distant object will be delivered to the eye as a narrow monocentric bundle of rays with its vertex (real or virtual, according as the lens itself is positive or negative) lying on a stigmatic image-surface that will be in contact with the far-point sphere of the mobile

eye on the axis of the lens and will not depart far from it anywhere; and hence when the eye turns to look through the glass, in the direction of the chief ray of the bundle, little or no effort of accommodation will be needed to focus the image of the object-point sharply on the sensitive retina.

It scarcely needs to be said that the precise shape of a spectacle lens that will give punctual imagery of this kind will depend on the actual specifications which are sometimes slightly different in some ways from those mentioned above, although, of course, the general principles of the various constructions are essentially the same in all of them. In this paper the discussion will be confined to an investigation of the form of the so-called Punktal lens as patented and made by the celebrated firm of Carl Zeiss in Jena, which is also made by the Bausch & Lomb Optical Company in this country. The theory of this construction has been very fully explained by v. Rohr and various other writers. For example, an entire chapter is devoted to this subject in O. Henker's excellent book on the "Theory of Spectacles" which has been recently translated in a kind of German-English, which however is quite comprehensible to an English or American reader who is already reasonably familiar with the subject. While this latter treatise particularly contains some accurate and useful numerical data concerning the actual construction of the Punktal lenses of different powers, nevertheless it is not possible to determine the curvatures that are used in each instance, and, as far as the writer is aware, these details of the construction have never been published. One of the principal objects of this paper is to try and ascertain the best possible form of a lens of given power that will fulfil the required conditions as far as necessary for practical purposes. Incidentally, a formula will be derived which takes into account the thickness of the lens, and which is applicable to any lens with a rear stop that is required to be free from astigmatism of oblique bundles of rays proceeding from the points of an infinitely distant object.

1. Some brief description of the meaning of the notation will be necessary in the first place. The vertices and centers of curvature of the two spherical surfaces of the lens will be designated by A_1, A_2 and C_1, C_2, respectively; the two radii and the axial thickness being denoted by $r_1 = A_1C_1$, $r_2 = A_2C_2$, and $d = nc = A_1A_2$, where n denotes the index of refraction of the glass and c denotes therefore the reduced

thickness. Accordingly, if the refracting powers of the single surfaces are denoted by

$$F_1 = (n - 1)/r_1 \text{ and } F_2 = -(n - 1)/r_2,$$

the refracting power of the lens as a whole will be

$$F = F_1 + F_2 - cF_1F_2.$$

However, the power of a spectacle lens is preferably expressed in terms of its vertex power (V), which is the reciprocal of the distance (v) of the second focal point of the lens (F′) from the vertex (A_2) of the surface that is nearer the eye, that is, the reciprocal of the so-called "back focus" of the lens ($v = A_2F'$). The refracting power and vertex power are, therefore, not identical unless the second principal point of the lens coincides with the vertex of the second surface, that is, unless the lens is infinitely thin ($c = 0$) or its first surface is plane ($F_1 = 0$). Moreover, except in the case of a lens that is symmetrical on both sides, the vertex power will be different according as the light traverses it one way or the other; whereas the refracting power of a lens surrounded by the same medium on both sides is independent of the direction of the light. The exact algebraic connection between these magnitudes is contained in the following equations:

$$\frac{F}{V} = 1 - cF_1 = \frac{F_1}{V - F_2}.$$

Let O, O′ designate the positions of a pair of conjugate points on the axis of the lens, and let O′ be supposed to coincide with the position of the center of rotation of the eye when the glass is adjusted in front of it. If the distances of O and O′ from the vertices A_1 and A_2 are denoted by z and z' ($z = A_1O$, $z' = A_2O'$) and the reciprocals of these magnitudes are denoted by the capital letters Z and Z' ($z \cdot Z = z' \cdot Z' = 1$), and if also we use the symbols

$$S = \frac{Z}{F}, \quad S' = \frac{Z'}{F}, \text{ and } \varphi = \frac{F_1}{F}$$

to denote the values of Z, Z' and F_1 for unit value of the refracting power ($F = 1$), then obviously, according to the ordinary laws for the refraction of paraxial rays through a thick lens, the function S may be expressed in terms of S' as follows:

$$S = \frac{(1 - c\varphi)\{S'(1 - c\varphi) - 1\}}{1 + c\{S'(1 - c\varphi) - 1\}}.$$

On the assumptions that the object is infinitely far away and that the refracting power of the lens is unity, the following equation* will be the condition of the abolition of the astigmatism of oblique bundles of rays:

$$\left\{(\varphi^3 - X)c^2 + (n-1)\left(n^3 - n\varphi - \varphi^2 + \frac{X}{n}\right)c - n^2(n-1)^2\right\}S^2$$
$$+ 2\left\{(\varphi^3 - X)c^2\varphi - (\varphi^3 - X + Y\varphi)c + Y\right\}S$$
$$- (1 - c\varphi)\left\{(1 - c\varphi)X + c\varphi^4\right\} = 0,$$

where the symbols X and Y are used for the sake of abbreviation to denote the following algebraic expressions:

$$X = n\left\{(n+2)\varphi^2 - n(2n+1)\varphi + n^3\right\},$$
$$Y = n(n-1)\left\{(n+1)\varphi - n^2\right\}.$$

If the expression given above is substituted in this equation in place of S, and if then φ and S' are eliminated by means of the relations

$$\frac{F_1}{\varphi} = \frac{Z'}{S'} = V(1 - cF_1),$$

an equation will be derived finally that will be of the 7th degree in F_1, namely,

$$HF_1^7 + JF_1^6 + KF_1^5 + LF_1^4 + MF_1^3 + NF_1^2 + PF_1 + Q = 0,$$

in which the coëfficients H, J, K, $\cdots$, P and Q are each functions of n, c, V and Z'. The expressions for these coëfficients are as follows:

$$H = \alpha_1c^7 + \alpha_2c^6 + \alpha_3c^5 + \alpha_4c^4,$$
$$J = \beta_1c^6 + \beta_2c^5 + \beta_3c^4 + \beta_4c^3,$$
$$K = \gamma_1c^5 + \gamma_2c^4 + \gamma_3c^3 + \gamma_4c^2,$$
$$L = \delta_1c^4 + \delta_2c^3 + \delta_3c^2 + \delta_4c,$$
$$M = \epsilon_1c^3 + \epsilon_2c^2 + \epsilon_3c,$$
$$N = \eta_1c^2 + \eta_2c + \eta_3,$$
$$P = \theta_1c + \theta_2, \qquad Q = \lambda;$$

*This formula can be readily derived from Seidel's formulae for the abolition of astigmatism (see, for example, Southall's *Mirrors, Prisms and Lenses*, p. 193). For the case of a single lens and an infinitely distant object (which is the special application to the problem of the Punktal lens), it was originally published by the writer in the J. O. S. A., *5*, p. 404; 1921, where, however, the symbols F_1 and S_1 were used instead of the present symbols ϕ and S. Unfortunately, the formula as it first appeared in print was marred by several typographical errors, which were afterwards corrected in the J. O. S. A. & R. S. I., *7*, p. 219; 1923.

where the Greek letters α, β, γ, δ, ϵ, η, θ, and λ are symbols which are defined as follows:

$$\alpha_1 = -n^2(1+V)V^6;$$

$$\alpha_2 = \{n^2-(2n+1)V-n(n+2)V^2\}V^4;$$

$$\alpha_3 = -\{n(n+2)(1+V)+2\}V^4;$$

$$-3\alpha_4 = \beta_4 = -\gamma_4 = 3\delta_4 = 3V^3;$$

$$\beta_1 = n^2\{2(n-1)(1+V)^2Z'+(6+7V)V^2\}V^4;$$

$$\beta_2 = 2\{n^2(1+V)+n(n^2-1)(1+V)V-V\}(1+V)V^2Z' + \{6n(n+2)V^2+5(2n+1)V-4n^2\}V^4;$$

$$\beta_3 = \{n(n+2)(4+5V)+8\}V^4-2(1+V)V^2Z';$$

$$\gamma_1 = -n^2[(1+V)Z'\{(n-1)^2(1+V)^2Z'+4(n-1)(2+3V)V^2\} + 3(5+7V)V^4]V^2;$$

$$\gamma_2 = \{n^2(1+V^3)+(3n^2-1-V)(1+V)V\}Z'^2 - 2[n^2(2+3V)Z'+(n^2-1)\{3(n+1)+4(2n+1)V+5nV^2\}VZ' + (5V-3n^2)V^2+10nV^3]V^2 - 15n(n+2)V^6;$$

$$\gamma_3 = 2\{(2+3V)Z'-3(n^2+2n+2)V^2-5n(n+2)V^3\}V^2;$$

$$\delta_1 = n^2[(n-1)^2(1+V)^2(2+5V)Z'^2 + 2(n-1)(6+20V+15V^2)V^2Z'+5(4+7V)V^4]V^2;$$

$$\delta_2 = 2[\{n^2+3(n^3+2n^2-n-1)V+6(n^2-1)(2n+1)V^2 + 10n(n^2-1)V^3\}Z' + \{10n(n+2)V^2+5(2n+1)V-2n^2\}V^2]V^2 - (1+V)\{3n^2(1+V)-1+3V)\}VZ'^2;$$

$$\delta_3 = 2[\{5n(n+2)V+2(n^2+2n+2)\}V^2-(1+3V)Z']V^2;$$

$$\epsilon_1 = -n^2\{(n-1)^2(1+V)(1+8V+10V^2)Z'^2 + 8(n-1)(1+5V+5V^2)V^2Z'+5(3+7V)V^4\}V^2;$$

$$\epsilon_2 = \{3n^2(1+V)-(2+3V)\}V^2Z'^2 - 2\{n^3+2n^2-n-1+2(n^2-1)(2+4n+5nV)V\}V^2Z' - \{15n(n+2)V^2+5(2n+1)V-n^2\}V^4;$$

$$\epsilon_3 = 2V^2Z'-\{5n(n+2)V+n^2+2n+2\}V^4;$$

$$\eta_1 = n^2\{(n-1)^2(3+12V+10V^2)Z'^2 + 2(n-1)(1+10V+15V^2)VZ'+3(2+7V)V^3\}V^3;$$

$$\eta_2 = \{(2n+1)V^2+6n(n+2)V^3+2(n^2-1)(1+2n+5nV)VZ' - (n^2-1)Z'^2\}V^3;$$

$$\eta_3 = n(n+2)V^5;$$
$$\theta_1 = -n^2\{(n-1)^2(3+5V)Z'^2 + 4(n-1)(1+3V)VZ' + (1+7V)V^2\}V^4;$$
$$\theta_2 = -n\{(n+2)V + 2(n^2-1)Z'\}V^3;$$
$$\lambda = n^2\{(n-1)Z' + V\}^2V^5.$$

Accordingly, when the values are given of the index of refraction of the glass and the distance of the center of rotation of the eye from the vertex of the second surface of the lens, that is, the numerical values of n and Z', these formulae will enable us to compute the corresponding values of the coëfficients H, J, K, etc., for any pair of prescribed values of the vertex power (V) and the reduced thickness (c) of the correction-glass; and then by solving the equation for F_1 the required form of the lens may be ascertained. For example, if we put n=1.52, Z'=40 dptr and V=4 dptr, the logarithms of α, β, γ, etc., will be found to be as follows:

$\lg \alpha_1 = 4.6750171 -$	$\lg \delta_1 = 7.2631992 +$
$\lg \alpha_2 = 4.4058710 -$	$\lg \delta_2 = 6.3335886 +$
$\lg \alpha_3 = 3.8669080 -$	$\lg \delta_3 = 4.6596777 +$
$\lg \alpha_4 = 1.8061800 -$	$\lg \delta_4 = 1.8061800 +$
$\lg \beta_1 = 5.9716823 +$	$\lg \epsilon_1 = 7.4287911 -$
$\lg \beta_2 = 5.6561889 +$	$\lg \epsilon_2 = 6.2819736 -$
$\lg \beta_3 = 4.4551625 +$	$\lg \epsilon_3 = 4.3830206 -$
$\lg \beta_4 = 2.2833012 +$	$\lg \eta_1 = 7.3276425 +$
$\lg \gamma_1 = 6.8048681 +$	$\lg \eta_2 = 5.9664747 +$
$\lg \gamma_2 = 6.1480236 +$	$\lg \eta_3 = 3.7386862 +$
$\lg \gamma_3 = 4.6826712 -$	$\lg \theta_1 = 6.9404576 -$
$\lg \gamma_4 = 2.2833012 -$	$\lg \theta_2 = 5.2673693 -$

and the value of λ is $\lambda = +1{,}455{,}092.138$. The formulae, however, are long and complicated, the numerical work being exceedingly laborious, as this example indicates. Theoretically an equation of the 7th degree will have seven roots, and not all of the real roots in this case are likely to be practical solutions of the problem. As a matter of fact, the particular form of the Punktal lens corresponds to a certain one of the real roots. Luckily, this special solution is not very difficult to find, because, as will be explained more fully presently,

an approximate value of it can be obtained by putting $c=0$ and solving the resulting quadratic equation. Consequently, in any given case we are by no means entirely at sea as to what the correct value of F_1 should be.

However, before proceeding with these tedious numerical calculations, it is desirable to obtain a clear notion of the limitations of the equation and also of the relative importance of the various factors. To begin with, it should be recalled that the Seidel formulae from which this equation was originally derived are themselves mere approximate expressions of the aberrations obtained by neglecting magnitudes of a certain order of smallness. The thickness of a spectacle lens is usually so inconsiderable in comparison with the other optical dimensions that it is practically almost entirely negligible. The thickness even in the case of the highest positive powers hardly ever exceeds 5 mm, and for the lowest negative powers it is not much over 1 mm. It is safe to assume that the maximum numerical value of c (expressed in meters if the power of the lens is given in dioptries) will be less than 0.005. For example, the coëfficient of F_1^7 in the above equation (denoted by H) contains no term that does not involve the fourth power of c at least; consequently, in the case of a spectacle lens this coëfficient is hardly worth considering at all. The same thing is practically true with respect also to the coëfficient J; and hence if we put $H=J=0$, the equation of the 7th degree reduces at once to an equation of the 5th degree. The truth is that under the circumstances the retention of these two terms is perhaps really more misleading than not.

2. Accordingly, let us begin by neglecting c entirely and considering, first of all, the case of an *infinitely thin lens* ($c=0$). This means that $H=J=K=L=M=0$ and that the vertex power $V=F$. If the values of the other coëfficients in this case are denoted by the same letters as before each with the subscript zero, then

$$N_0 = \mathrm{n}(\mathrm{n}+2)F^5;$$
$$P_0 = -2\mathrm{n}(\mathrm{n}^2-1)F^5Z' - \mathrm{n}(\mathrm{n}+2)F^6;$$
$$Q_0 = \mathrm{n}^2\{(\mathrm{n}-1)Z'+F\}^2F^5.$$

The equation of the 7th degree reduces now to a quadratic equation of the form

$$\alpha F_1^2 + \beta F_1 + \gamma = 0, \qquad (c=0),$$

where

$$\alpha = n + 2, \quad \beta = 2(n^2 - 1)Z' - (n + 2)F,$$
$$\gamma = n\{F + (n - 1)Z'\}^2.$$

For given values of n and Z' this equation referred to a pair of rectangular axes, with the variables F and F_1 as coördinates will be found to represent an ellipse (the "Tscherning curve," as it is called in Henker's *Introduction to the theory of spectacles;* see the diagram Fig. 117 in which the curve is plotted with the abscissae to denote the refracting power of the infinitely thin lens in dioptries and the ordinates to denote the refracting power of the first surface). This closed curve lies wholly on the positive side of the F_1-axis, although this axis is tangent to the ellipse at the point whose coördinates are $F = -(n-1)Z'$, $F_1 = 0$. The form of the lens corresponding to this particular point is indeed plano-concave, but corresponding to all other points on the ellipse the lens will be a meniscus with the radii of both surfaces positive in sign. For $n = 1.52$, which is the usual value of the index of refraction of the glass used in ordinary spectacles, the two extreme values of F will be found to be $F = +0.19452 \cdot Z'$ and $F = -0.6170 \cdot Z'$, and consequently all so-called Punktal lenses are practically comprised within this range of powers. The most common value of Z' is $Z' = 40$ dptr corresponding to an interval of 25 mm along the axis between the nearer side of the glass and the center of rotation of the eye. Thus for $n = 1.52$ and $Z' = 40$, the limiting values of F prove to be $+7.78$ and -24.68 dptr. Since no concave spectacle lenses will exceed -20 dptr, the negative limit here is ample for the highest degree of myopia. On the other hand, cases of hypermetropia do occur where the power of the required correction-glass may be as much as $+10$ dptr, and an aphakic eye in which the crystalline lens has been removed will be apt to need a positive lens of considerably higher power even than this. Thus while Tscherning's ellipse extends far enough over on the negative side of the F-axis of coördinates, it falls a little short on the positive side, although even here it extends far enough for the great majority of actual cases for which a positive glass is needed. The lower part of the ellipse comprised between the two tangents that are parallel to the vertical F_1-axis of coördinates is known as the Ostwalt branch of the curve, the upper portion being called the Wollaston branch. The form of the Punktal lens corresponds to the smaller of the two roots of the quadratic equation, that is, to the Ostwalt branch of Tscherning's ellipse. These lenses

are, therefore, shallower than the Wollaston type of lenses of the same power; in fact, the latter are generally rather too deep and inconvenient to be worn as spectacles and are therefore not manufactured as a rule.

If the magnitudes F_1 and Z' in the above quadratic equation are replaced by $\varphi \cdot F$ and $S' \cdot F$, respectively, an equation will be obtained between φ and S' as variables which may be written as follows:

$$2(n+2)\varphi - 2(n^2-1)S' - (n+2) = \pm 2(n-1)\sqrt{(S'-x_1)(S'-x_2)}, \qquad (F=1),$$

where x_1 and x_2 are convenient abbreviations of the two algebraic expressions

$$\frac{(n+2)(n-1) \pm n\sqrt{n(n+2)}}{2(n-1)}.$$

When this equation is plotted with reference to a pair of rectangular axes whose coördinates are (S', φ), the curve that is obtained will be an hyperbola one of whose diameters is the straight line

$$2(n+2)\varphi - 2(n^2-1)S' - (n+2) = 0,$$

which meets the curve in the two points whose coördinates are:

$$S' = x_1, \qquad \varphi = \frac{n}{2}\left\{n + \frac{(n-1)\sqrt{n(n+2)}}{n+2}\right\}$$

and

$$S' = x_2, \qquad \varphi = \frac{n}{2}\left\{n - \frac{(n-1)\sqrt{n(n+2)}}{n+2}\right\}.$$

Between $S'=x_2$ and $S'=x_1$ there are no real values of φ, but for all values of S' outside this interval, there will always be two real values of φ. For example, on the assumption that $n=1.52$, the equation of the hyperbola becomes:

$$6.76923\varphi - 2.5200S' - 3.3842 = \pm\sqrt{(S'-5.1798)(S'+1.6598)}.$$

For $F=+6$ dptr and $Z'=+40$ dptr, the value of S' is $S'=+6\frac{2}{3}$ dptr, and for this value of S' the two values of φ will be $\varphi=+2.41696$ and $\varphi=+3.50155$; consequently, we obtain in this case $F_1=+14.502$ dptr (corresponding to the Punktal form) and $F_1=+21.009$ dptr (Wollaston type).

3. Having considered first the case of an infinitely thin lens, let us now return to the general case as represented by the equation

of the 7th degree in F_1. The numerical values of the coëfficients H, J, K, etc., have been computed for two typical cases in each of which $n=1.52$ and $Z'=40$ dptr.

Case 1. Vertex power, $V=+4$ dptr; thickness, $d=nc=0.003$ m.

$$H = -1193114 \times 10^{-15}; \qquad M = -55.33859;$$
$$J = +1922575 \times 10^{-12}; \qquad N = +7\ 388.700;$$
$$K = -1139709 \times 10^{-9}; \qquad P = -202\ 292.3$$
$$L = +3210912 \times 10^{-7}; \qquad Q = +1\ 455\ 092.$$

The required root in this case is very nearly $F_1=+12.05$ dptr; and hence the radii of the two surfaces of the lens must be $r_1=+43.15$ and $r_2=+62.32$ mm.

The form of the lens having thus been ascertained, the next thing to be done is to calculate the astigmatism of a narrow bundle of parallel incident rays whose chief ray after emerging from the lens crosses the axis at the point O′ ($A_2O'=25$ mm) at a certain selected slope. The ray chosen for this purpose (corresponding to the data in Henker's book) was the one that was inclined to the axis of the lens at an angle of 28° ($\theta_2=-28°$), which is about the angular measure of the semi-diameter of the field of fixation of the mobile eye. The astigmatism is the difference between the convergence of the pencil of meridian or tangential rays (A_2') and that of the pencil of sagittal rays (B_2'); and with the above data its value in round numbers is $A_2'-B_2'=-0.08$ dptr. While this amount of oblique astigmatism may be considered as practically negligible, it is actually about eight times as much as Henker gives for the Zeiss Punktal lens of the same vertex power and axial thickness. Consequently, this long calculation does not enable us in this instance to find the exact form of the Punktal lens.

Case 2. Vertex power, $V=+8$ dptr; thickness, $d=nc=0.005$m.

$$H = -1410243 \times 10^{-13}; \qquad M = -3\ 725.887;$$
$$J = +1702760 \times 10^{-10}; \qquad N = +301\ 160.6;$$
$$K = -8880752 \times 10^{-8}; \qquad P = -7\ 834\ 748.;$$
$$L = +23.81681; \qquad Q = +62\ 794\ 569.$$

Here we find for the required root of the equation the value $F_1=+17.6884$ dptr. (There happens to be also another root in the vicinity of this one, namely, $F_1=+19.059$; which corresponds to a point on the Wollaston portion of Tscherning's ellipse, near the place where it unites with the Ostwalt branch. However, we are not concerned

with this other root at present.) Trigonometrical calculation of the astigmatism of this lens under exactly the same conditions as in *Case 1* above gives a result about twice as great as the astigmatism of the Zeiss Punktal lens of the same vertex power and axial thickness as given by Henker.

4. These two typical numerical examples seem to indicate very definitely that the equation of the 7th degree cannot be relied on to give precisely the best form of spectacle lens that most nearly fulfils the condition of freedom from astigmatism of oblique bundles of rays; as indeed might have been anticipated from the previous discussion of the formula. The truth is that, so far as this requirement is concerned, the simple quadratic equation in F_1 obtained by neglecting the thickness of the lens leads to a determination of the approximate form of the glass that is perhaps quite as satisfactory for "bending" the lens into its final most perfect shape as the solution that results from the far more laborious calculation. Nevertheless, the longer formula does possess a certain interest, because it is not only applicable to a spectacle lens of very slight thickness but to a lens of any dimensions whatever.

The result of this investigation, however, has been to convince the writer that after all the only way of ascertaining the *best* form of a Punktal spectacle lens is by the ordinary process of exact trigonometrical calculation, according to some such actual method as that which is outlined below. We shall have to begin the calculation by assigning a value to F_1 that is approximately the same as that given by the ordinate to the Ostwalt branch of Tscherning's ellipse which corresponds to a value of F equal to that of the given vertex power V. The refracting power of the second surface of the lens will be

$$F_2 = V - \frac{F_1}{1 - cF_1},$$

and accordingly the radii r_1 and r_2 can both be computed. It may be assumed in all these calculations that $n = 1.52$ and $z' = 0.025$ m. In the subsequent numerical examples the inclination of the chief ray to the axis of the lens is supposed to be 30°, that is, $\theta_3 = -30°$. The path of this ray must be computed, and for this purpose the following system of formulae is convenient:

$$x_2' = z' - r_2,$$

$$\sin \alpha_2' = -\frac{x_2' \sin \theta_3}{r_2}, \qquad \sin \alpha_2 = \frac{\sin \alpha_2'}{n},$$

$$\theta_2 = \theta_3 - \alpha_2' + \alpha_2, \qquad x_2 = -\frac{r_2 \sin \alpha_2}{\sin \theta_2},$$

$$a = r_2 - r_1 + d, \qquad x_1' = x_2 + a,$$

$$\sin\alpha_1' = -\frac{x_1' \sin \theta_2}{r_1}, \qquad \sin \alpha_1 = \mathrm{n} \sin \alpha_1'.$$

Here α_1, α_1' and α_2, α_2' denote the angles of incidence and refraction at the first and second surfaces of the lens, respectively. If the path of the ray in glass crosses the axis of the lens at M, then $x_1' = C_1M$, $x_2 = C_2M$ are the distances of M as measured from the centers of curvature of the two surfaces. Moreover, $x_2' = C_2O'$ and $a = C_1C_2$.

The astigmatism $(A_2' - B_2')$ along this ray may then be computed by obtaining first the values of D_1, D_2, h_1, h_2 and t, as defined by the following expressions:

$$D_1 = \frac{\sin (\alpha_1 - \alpha_1')}{r_1 \sin \alpha_1'}, \qquad D_2 = \frac{\mathrm{n} \cdot \sin (\alpha_2 - \alpha_2')}{r_2 \sin \alpha_2'},$$

$$h_1 = r_1 \sin (\alpha_1 - \theta_1), \qquad h_2 = r_2 \sin (\alpha_2 - \theta_2),$$

$$t = \frac{h_2 - h_1}{\mathrm{n} \cdot \sin \theta_2}.$$

Since $A_1 = B_1 = 0$ is the condition that the narrow bundle of incident rays shall be cylindrical (emanating therefore from a point in an infinitely distant object), the required values of A_2' and B_2' for the bundle of emergent rays may be computed as follows:

$$B_1' = D_1, \qquad A_1' = \frac{D_1}{\cos^2 \alpha_1'},$$

$$B_2 = \frac{B_1'}{1 - tB_1'}, \qquad A_2 = \frac{A_1'}{1 - tA_1'},$$

$$B_2' = B_2 + D_2, \qquad A_2' = \frac{P_2 \cos^2 \alpha_2 + D_2}{\cos^2 \alpha_2'}.$$

Suppose that having given F_1 a certain value $F_1 = a$, we find $A_2' - B_2' = b$; and that for another value $F_1 = a'$ (where a' is reasonably close to a), the astigmatism amounts to b'; then if

$$\frac{a' - a}{b' - b} = \epsilon, \qquad u = b\epsilon, \qquad \text{and } u' = b'\epsilon,$$

according to the theory of interpolation, the astigmatism may be expected to vanish entirely for a value of $F_1 = a''$, where

$$a'' = a - u = a' - u'.$$

Accordingly, we proceed then to see if this is the case. It may be that the astigmatism does not absolutely vanish for any value of F_1, and in that case the best we can do is to find out if possible what value of F_1 will give the minimum astigmatism. This process of successive trigonometrical computation until we succeed in obtaining finally the most suitable value of F_1 is also very laborious; but in the end it enables us to determine as accurately as possible the most satisfactory form of the required lens for the given values of V and c.

Some typical numerical results are appended, the calculations in all cases being for the values $n = 1.52$, $Z' = 40$ dptr, and $\theta_3 = -30°$.

(1) Vertex power, $V = +4$ dptr; thickness, $d = 3$ mm; $F_1 = +10.66$ dptr; $F_2 = -6.89103$ dptr; radii, $r_1 = +48.78$ mm, $r_2 = +75.48$ mm; refracting power, $F = +3.914$ dptr; astigmatism, $A_2' - B_2' = +0.00005$ dptr.

(2) Vertex power, $V = +6$ dptr; thickness, $d = 4$ mm; $F_1 = +12.93$ dptr; $F_2 = -7.38546$ dptr; radii, $r_1 = +40.217$ mm, $r_2 = +70.409$ mm; refracting power, $F = +5.796$ dptr; astigmatism, $A_2' - B_2' = +0.00022$ dptr.

(3) Vertex power, $V = +8$ dptr; thickness, $d = 5$ mm; $F_1 = +16$ dptr; $F_2 = -8.88673$ dptr; radii, $r_1 = +32.500$ mm, $r_2 = +58.514$ mm; refracting power, $F = 7.581$ dptr; astigmatism, $A_2' - B_2' = +0.0855$ dptr. (The astigmatism is found to have about the same value also for $F_1 = +17$ dptr, which would seem to indicate that the minimum value of the astigmatism for $V = 8$ and $d = 0.005$ was about 0.1 dptr; but for the Punktal lens of this power the astigmatism according to Henker's data is only +0.05 dptr.)

(4) Vertex power, $V = -2$ dptr; thickness, $d = 1.4$ mm; $F_1 = +7.5$ dptr; $F_2 = -9.5522$ dptr; radii, $r_1 = +69.33$ mm, $r_2 = +54.438$ mm; refracting power, $F = -1.9862$; astigmatism, $A_2' - B_2' = +0.004$ dptr.

By way of comment, it may be noted that the value $F_1 = 10.66$ for $V = +4$ and $d = 0.003$ is quite different from the value $F_1 = 12.04$ that was obtained above by using the equation of the 7th degree in F_1. The astigmatism of a Punktal lens of this power amounts to -0.01 dptr; whereas it is only $+0.00005$ for $F_1 = 10.66$.

For the case when $V = 6$, $d = 0.004$, Henker gives -0.03 dptr for $A_2' - B_2'$, whereas for $F_1 = +12.93$, the value of the astigmatism is only $+0.00022$ dptr.

For $V=-2$, $d=0.0014$, Henker's value is -0.01, whereas for $F_1=+7.5$, the value obtained is only $+0.004$. (The writer does not know whether Henker's measure of the astigmatism is $A_2'-B_2'$ or $B_2'-A_2'$, so that in comparing his numerical data with the results that are obtained here, it is simply a comparison of the absolute amount of the astigmatism, without taking into account the sign of this magnitude.)

It is hoped that these results will be of some service especially to manufacturers of spectacle lenses.

DEPARTMENT OF PHYSICS,
COLUMBIA UNIVERSITY,
NEW YORK CITY,
JULY 2, 1926.

A Sensitive Galvanometer of Short Period and Low Resistance.—In an instrument needed by the author for lagless indication of thermocouple temperatures the following characteristics were required: Period about .01 second; critical damping, independent of external resistance; high voltage sensitivity with resistance not to exceed 10 ohms. For his purpose the ordinary oscillograph and string galvanometer were not sufficiently sensitive. His design may be regarded as a compromise between a string galvanometer and an ordinary moving coil galvanometer. A single suspension, consisting of a silicon bronze strip, is held under tension in the field of an electromagnet, parallel to and near one of the pole pieces of the latter. This suspension constitutes the axis about which the "coil" rotates. The moving "coil" consists of a length of very thin copper wire parallel to the suspension strip, with its ends bent at right angles and soldered to the strip. The portion of the suspension fiber between the soldered junctions of the moving "coil" constitutes a shunt about the latter, and on account of the difference in resistances between the two paths, the greater part of the current flows through the copper wire. The torque is produced by the interaction between magnetic field and the current in the copper wire. The asymmetry of the arrangement is a mechanical disadvantage which is overcome by mounting the mirror in such a manner on the side of the suspension opposite the "coil" that the center of mass of the whole system lies in the axis of rotation. The length of the "coil" is 21 mm and the distance of its active conductor from the suspension is .18 mm. The total length of the suspension strip is 38 mm. The system is exceptionally light and strong, and hence requires no arrestment. The period of the instrument is about .01 second and its current sensitiveness with a resistance of 10 ohms, is 0.3×10^{-6} amp/mm at one meter scale distance. [W. J. D. van Dyck, (University of Utrecht) ZS. f. Instrk., *46*, pp. 378–380; 1926.]

P. E. K.

AN ELECTROMAGNETIC SEPARATOR FOR LABORATORY USE

By Charles J. Ksanda

A useful instrument in the chemical or mineralogical laboratory, for the purpose of separating minerals for analysis, is an electromagnet. Taking advantage of differences in magnetic susceptibility, the investigator can bring a finely powdered mineral mixture to the necessary effective distance from the pole pieces, to which the more magnetic portions will adhere. By breaking the current and repeating the process on successive fractions a high degree of separation can be obtained.

The instrument described here does not differ greatly from the original principle used by Fouqué or Delesse, except in its design as an accurate comparative instrument, by which the relative magnetic susceptibilities of minerals can be estimated with greater speed and accuracy, and fractionation be correspondingly facilitated.

As we have had numerous inquiries about the details of construction of the instrument in use in this Laboratory, full specifications and working drawings are here placed on record for the benefit of others who may be interested. The magnetic circuit is made of Armco ingot forged iron, thoroughly annealed before finishing, insuring thus low retentivity of magnetism. The crossbar (see Fig. 1) extends over the core pieces on the front and back, as well as on the sides, to ensure passage of practically all the magnetic flux through the iron; for the same reason the pole pieces are made somewhat heavier than the cores. One of the pole pieces is grooved and carefully fitted to move smoothly on a track and at the same time to make continuous perfect contact with the central iron core. Both poles are terminated with heavy ends, the inner sides having a slope of 45°, thus producing a concentrated electromagnetic field.

By means of a micrometer screw, made of hard bronze, and a graduated knob, the horizontal distance or space between the poles can be varied and duplicated within 0.1 mm from 0 to 15 mm.

A support is provided for a glass plate to prevent the particles from coming in contact with the pole pieces. Its distance can be varied in the vertical direction by means of a rack and pinion arrangement, and can be duplicated by means of a graduated scale and index.

The winding consists of two spools made of light brass, upon each of which is wound 5500 turns of No. 20 (0.0320 inch or 0.8118 mm) "silkenite" (single silk covered enameled) copper magnet wire. The ends of each winding are brought to a connecting binding post, mounted on a bakelite base, through an insulating sleeve of hard rubber, in order to connect the spools either in parallel or in series. The winding on the spools is covered with imitation leather for protection.

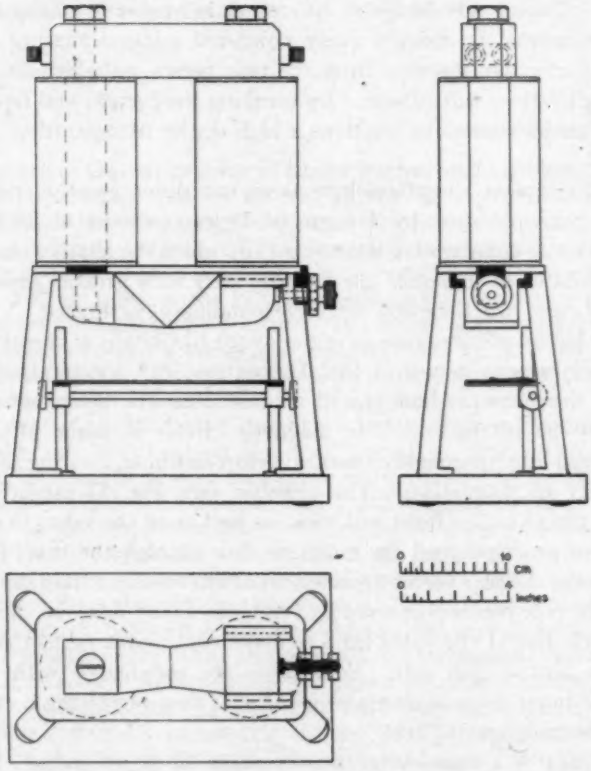


FIG. 1. *Working drawings of electromagnet, drawn to scale.*

The legs supporting the spools and iron poles are 7½ inches (19 cm) high, providing sufficient working space and ample light while in use. They are made of bronze, mounted on a hardwood base. The electromagnet is designed to operate directly on 110 volts direct current with

safety, and carries about 1.95 amperes, but a lower voltage may be used if desired.

A simple foot-switch is in circuit to close the connection and to open it automatically when the electromagnet is not in use.

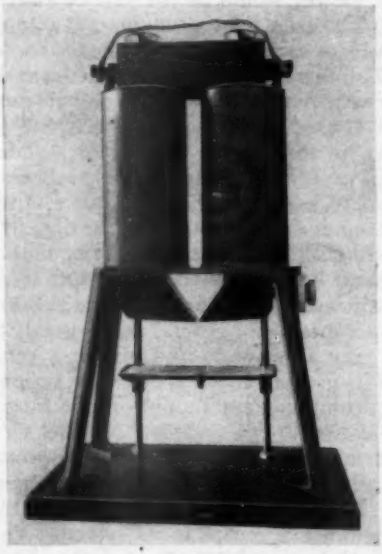


FIG. 2. *Photograph of electromagnet and accessories, complete.*

All other parts and screws, except the magnetic circuit, are made of brass or other non-magnetic material. The total weight of the finished instrument is 46 pounds (21 kilograms). Fig. 2 is a photograph of the instrument.

GEOPHYSICAL LABORATORY,
CARNEGIE INSTITUTION OF WASHINGTON,
WASHINGTON, D. C.,
AUGUST, 1926.

The Decimal Bibliographical Classification.—By A. F. C. Pollard; 109 pages; Cambridge University Press, 1926.

Obviously science must classify sources and data which would be chaotic and practically inaccessible otherwise. The ways in which any subject may be classified are unlimited. If every man of science tried his hand no two outlines would be alike. Nor would any be acceptable to its author ten years hence. Classifiers know that only a perfected

science would permit an enduring classification from any point of view. A classification is therefore a set of pigeon holes to accommodate sources and data today. Tomorrow is another story.

The famous Dewey classification adopted by most American libraries is the master work of a library genius, easy to criticise, difficult to excel. Actually, however, Dewey would be the first to assert that to prepare the classification is far easier than to engineer it into general use. The Brussels bibliographical decimal classification is based upon Dewey's famous decimal classification. Pollard's abridged translation is welcome as a forward step with reference to optics and related subjects. The larger classification is used by the Verein Deutscher Ingenieure which prints bibliography in form to be clipped to standard card size for filing behind guides numbered according to the Brussels outline. The same outline is widely used in Belgium, France, and Germany.

Pollard's translation is intended to make the optical and related outlines accessible to English optical science. It is doubtless the best for use until some general body takes the important step of accepting or formulating a classification. Perhaps, indeed, the Brussels classification may appeal as acceptable for general use. Possibly the International Research Council may approve it and give it a sanction which will still further extend its use and add this desirable action to the very successful enterprise of compiling and publishing the International Critical Tables. The publication of the complete Manuel du Repertoire Bibliographique Universal would lend the weight of approval to a classification which has already been of great service in putting our bibliographical house in order. Parts I and II are full of the most practical suggestions for the maintenance of a card index system. The typography of the Cambridge Press is, as usual, excellent. Subordination is indicated in the manner originated by Dewey in three ways, by the decimal place in the key number, by the size of type, and by indentation.

H. D. H.

Procedure for forming transparent films of metal.—The film is deposited by cathode sputtering on a highly polished surface of a rocksalt crystal, which is then dissolved away by a stream of water; by first covering the central area of the surface with a circular piece of glass and sputtering for some time, a ring of thicker metal is formed to serve as a frame for the thin sheet. This latter may be only 5mμ thick if its diameter does not exceed 5mm, while circular sheets of 3 to 4cm diameter and only 30–40mμ thick have been produced out of Ag, Au, Pt, Ni and Cu. The films are "highly elastic and extraordinarily strong", a 30mμ sheet of silver sustaining a pressure difference of 8mm Hg between its sides, and being able to vibrate with loudly audible tones without being ruptured. [K. Lauch and W. Ruppert, Phys. ZS., *27*, pp. 452–454; 1926.]

KARL K. DARROW

A NEW HYGROMETER

By Arnold Romberg and L. W. Blau

ABSTRACT

The hygrometer described is continuous-indicating; a value of the humidity is obtained by balancing a column of atmospheric air against a column of air saturated with water vapor and observing the effect, on a suspended vane, of the difference of pressure due to the different densities. The instrument used in the investigation is more sensitive than the Regnault-Alluard type of dew-point hygrometer and can be made a hundred times as sensitive if required.

Since the density of water vapor is less than that of dry air the hygroscopic condition of the atmosphere may be ascertained by comparing its density with that of air which is completely saturated with water vapor. This principle is employed in the hygrometer to be described in the following pages.

Essentially the apparatus consists of two long vertical tubes both of which are in communication at their lower extremities with a vessel containing water. If now one of these be closed near its lower end by a stopcock and the apparatus left undisturbed until the water vapor has diffused up into the other tube, circulation of air through the apparatus will commence as soon as the stopcock is opened. This circulation is due to the difference in density of the two air columns. If the instrument is standing in a completely saturated atmosphere there will be no circulation. By a suitable arrangement the current due to the difference in density may be caused to produce an easily observable effect.

Fig. 1 shows a photograph of the instrument. The vessel A contains water the level of which may be observed by means of the gauge G which also permits the insertion of a thermometer to obtain the temperature of the instrument. The exhaust tube B is 45 cm long and contains a column of air completely saturated with water vapor on account of its having passed at a slow speed over the water in the saturator A. The tube C which serves as the intake tube is interrupted near its middle by the box D; the upper extremity of this tube fits into the bottom of the box as indicated in Fig. 2. At C' is the lower end of another tube, the virtual continuation of tube C, which is soldered to the tube B along nearly its entire length to equalize the temperature. In the box D is a partition P nearly equal in length to the radius of the box; this partition serves to guide the incoming air

from C' so as to turn the vane V. The latter, Fig. 3, is made of mica and has weights Z at each end to increase the moment of inertia and thereby the period of the system. The vane is suspended by means of a phosphor bronze ribbon (0.002″) 12 cm long from the torsion head T; its period is 40 seconds but damped nearly critically. A mirror M permits the observation of the rotation of the vane through the plate glass window W, with telescope and scale. The latter are not shown.

Calculation shows that the time required to saturate the air space in the saturator A by diffusion is less than twenty seconds. Under extreme conditions of relative humidity and temperature the calculated

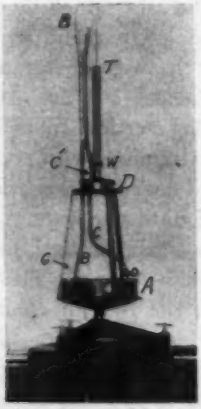


FIG. 1. *The hygrometer.*

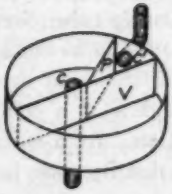


FIG. 2. *Box D with vane.*

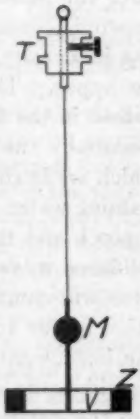


FIG. 3. *The suspended system.*

consumption of water is about one-fourth gram per day; in ordinary conditions perhaps less than forty grams of water would be evaporated per year.

It was to be expected that the deflection of the vane would be directly proportional to the difference in density of the two air columns and therefore to the rate of flow through the tubes. To test this, air was caused to flow through the apparatus at certain definite rates up to 17.1 cubic centimeters per minute. The plot of the deflection against the flow in cubic centimeters per minute is a straight line as shown in Fig. 4.

For calibration the instrument was placed in a metal container three feet high and having a capacity of 3.3 cubic feet. A dew-point

hygrometer of the Regnault-Alluard type was placed in the container with the instrument. This dew-point instrument was cooled by means of water which had been previously cooled to approximately the dew-point temperature.[1] Three thermometers were placed in the calibrating container; one was in the tube *G* of the new hygrometer, one in the dew-point instrument, and one was suspended from the top of the container. An electrically driven fan served to stir the air

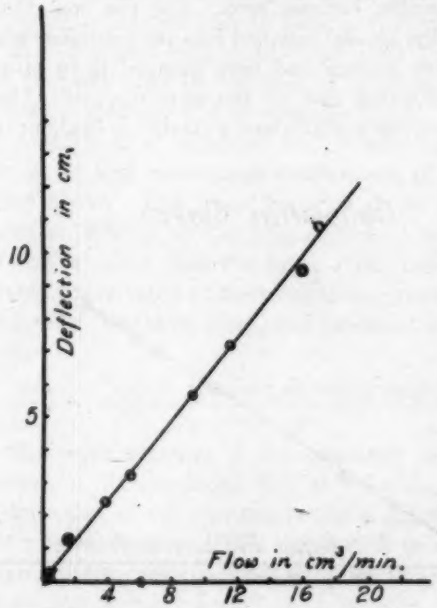


FIG. 4. *Deflection due to flow through instrument.*

vigorously before observations were made. The air inside was dried by circulating it through two long tubes of calcium chloride by means of a pump until approximately the desired humidity was attained. Much time was required to equalize the temperature and no data were taken unless the three thermometers showed the same temperature

[1]Cooling the dew-point hygrometer with ether was found to be impractical on account of the fact that it was difficult to prevent the escape of small quantities of ether from the dew-point instrument. Since ether vapor is soluble in water it was taken up by the water after its passage through the tube CC′, and since its density is greater than that of air, the presence of ether vapor increased the deflection of the new hygrometer, for under the circumstances the tube *CC′* contained a mixture of greater density than when the ether vapor was absent.

at the beginning of the experiment. The cold water was drawn through the dew-point instrument by means of an aspirator. The plot of the deflection against the difference between the vapor pressure of water at room temperature and the vapor pressure of water at the dew-point is a straight line, as shown by the calibration curve, within the limits of error of the dew-point hygrometer; cf. Fig. 5.

The container was finally saturated with water vapor with the result that the deflection became zero. The fan was then started and 95 per cent ethyl alcohol pumped into the container while the fan was running. When enough had been pumped in to saturate the inside completely the pump and the fan were stopped. The deflection increased immediately and attained a maximum in about twenty minutes.

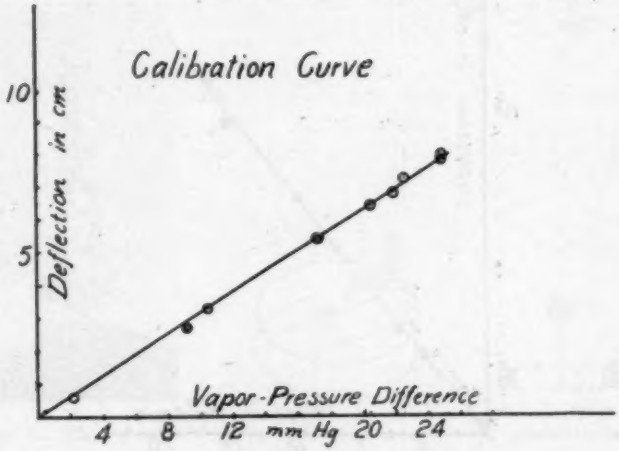


FIG. 5

The tube CC' then contained alcohol vapor plus saturated water vapor; tube B contained saturated water vapor. The alcohol vapor was absorbed by the water in the saturator A, leaving a difference of pressure due to the alcohol between tubes B and CC'. The deflection thus obtained also lies on the straight line if we assume that in these circumstances the vapor pressure of 95 per cent alcohol is 95 per cent of the vapor pressure of absolute alcohol at the same temperature under these conditions; this is at least a fair approximation.

The force which drives the air is directly proportional to the excess of moisture in the saturated air, over that in the room; this is true irrespective of the temperature and pressure. If the resulting flow

is slow enough, it may be assumed to be resisted by a force proportional to the flow. A part of this resistance is that offered by the vane suspended in the air current. If this part of the resistance is of the same nature as the rest—practically all of it due to viscosity at the low speeds used—the deflection will be proportional to the driving force and therefore to the excess of moisture mentioned. As far as the calibration has been carried out this is true in the present instrument, but if more accurate calibration should show a discrepancy it will be easy to make an instrument with small-bore[2] tubes and with a vane whose plane is perpendicular to the axis of rotation, in which the resistance is even more nearly due to viscosity alone.

The tube B contains fully saturated water vapor at all times, for the circulation of air and consequent evaporation of water is very slow as indicated above. This water vapor is at the same temperature as the room or, strictly, at the temperature of the water in the saturator A if this is colder than the room. The tube CC' contains partially saturated water vapor at the same temperature, for the tubes are soldered together; we have, then, the following relation for the relative humidity:

$$\text{Rel. Hum.} = \frac{{}_TP_V - \text{vapor pressure of water vapor in tube } CC'}{{}_TP_V}$$

where ${}_TP_V$ is the vapor pressure of the saturated vapor in tube B at room temperature. It was found that at the scale distance used, 58.5 cm, the deflection is one centimeter for a difference of vapor pressure of 3.16 mm of mercury. This corresponds to a pressure head of 0.000077 grams per square cm driving the air through the instrument. Hence we may write,

$$\text{Rel. Hum.} = \frac{{}_TP_V - 3.16 \cdot \text{deflection}}{{}_TP_V}.$$

The sensitiveness of the instrument may be increased by employing a suspension of smaller torsion coefficient and by increasing the length of the tubes. The hygrometer which was used in this work was more sensitive than a dew-point instrument, and its sensitiveness can be increased a hundred times.

[2]The tubes of the instrument used in the investigation have an inside diameter of 0.8 cm. It was found that air currents caused erratic deflections, and the viscosity was subsequently increased by inserting tubes having an inside diameter of 0.4 cm into the tubes of the instrument. After this was done the deflections became very steady indeed.

There are two sources of disturbance, air currents and temperature gradients. The latter, in so far as they might be harmful, are avoided by soldering the two tubes together along nearly their entire length. The ordinary air currents of the laboratory produced occasional deflections which, however, did not usually interfere with readings. This trouble can be further reduced by modifying the design, and it is hoped that an out-door instrument may be produced. One might also be led to think that the evaporation of the water in the saturator *A* would cause a lowering of the temperature which would influence the accuracy of the instrument. However, since the evaporation would never exceed 0.25 grams in twenty-four hours no appreciable error would be introduced. The hygrometer apparently does not reverse even when exposed repeatedly in saturated air.

The instrument has certain outstanding and obvious advantages over the other hygrometers now in use. Among these might be mentioned:

(a) Ease of observation, requiring only the obtaining of the deflection and of the temperature, a task which may well be entrusted to the least skilled observer. Table 1 shows in an abbreviated manner how a set of values of the relative humidity may be computed for different deflections and temperatures, thus permitting the obtaining of the relative humidity from these data. It is obvious, then, that the method of obtaining a value of the relative humidity is no more complicated than with other hygrometers which can lay any claim to accuracy. (b) The instrument is continuous-indicating and permits of graphical recording. (c) It is equally adapted to extreme winter or summer temperatures. (d) The instrument is potentially a vapor-pressure apparatus. (e) It is a micromanometer of extreme sensitiveness; for a pressure head of 0.00075 dynes per square cm produces a readable deflection, and there may be applications in fields other than hygrometry. (f) The instrument is portable and may be set up anywhere without disturbing the calibration if carefully leveled.

The same principle may be employed in other forms of hygrometers by changes of construction. For instance, dry air may be used as a balancing column. *A* helix suspended in a long tube may take the place of the box *D* and of the suspended system. A thin, horizontal vane has been used instead of the vertical while the work was in progress.

TABLE 1. *Relative humidity for deflections and temperatures ranging from zero to 13.3 cm and from −15°C to 35°C, respectively. Scale distance 58.5 cm.*

Deflection cm	−15	−10	−5	0	5	10	15	20	25	30	35
0	100	100	100	100	100	100	100	100	100	100	100
0.1	75	84	89.6	93.1	95.1	96.5	97.4	98.2	98.7	98.9	99.2
0.2	50.5	68.0	79.1	86.2	90.3	93.1	95.0	96.3	97.3	97.9	98.5
0.3	23.8	52.0	68.7	79.3	85.4	89.6	92.5	94.5	95.9	96.9	97.7
0.4	0	36.0	58.3	72.3	80.4	86.2	90.0	92.7	94.6	95.9	96.9
0.5		20.0	47.9	65.4	77.3	82.7	87.5	90.9	93.3	95.0	96.2
0.6		4.0	37.5	58.3	70.8	79.2	85.0	89.8	91.9	94.0	95.5
0.7		0	27.0	51.6	66.0	75.8	82.6	87.3	90.6	93.0	94.7
0.8			16.6	44.7	61.1	72.3	80.1	85.4	89.2	92.0	93.9
0.9			6.2	37.7	56.3	68.9	77.6	83.6	87.9	90.9	93.2
1.0			0	30.8	51.4	65.4	75.1	81.8	86.6	89.9	92.4
1.4				3.4	32.0	51.6	65.1	74.5	81.2	85.9	89.4
1.5				0	27.2	48.1	62.6	72.7	79.8	84.9	88.6
2.0					2.9	30.9	50.1	63.6	73.1	79.9	84.8
2.1					0	27.4	47.6	61.8	71.4	78.9	84.0
2.8						3.2	30.2	49.0	62.4	71.9	78.8
2.9						0	27.7	47.2	61.0	70.9	78.0
4.0							0.3	27.2	46.2	57.9	69.8
4.1							0	25.4	44.9	58.9	69.0
5.4								1.1	27.4	43.8	59.2
5.5								0	26.1	44.8	58.4
7.4									0.5	25.8	44.0
7.5									0	24.8	43.3
9.9										0.7	25.1
10.0										0	24.4
13.2											0.2
13.3											0

Further investigation is in progress with a view to increasing the portability and freedom from disturbances, and designing an arrangement for recording graphically.

PHYSICAL LABORATORY,
UNIVERSITY OF TEXAS,
AUSTIN, TEXAS,
JULY 12, 1926.

Narrowing of the gap between x-rays and the ultraviolet.—By employing a dispersing crystal consisting of a thin film of one of the organic substances (melissic acid) lately studied by de Broglie and Friedel, having a spacing of 87A between successive molecule-layers, Dauvillier is able to diffract rays as great as 138A in wave length (he does not actually state that such a ray was observed, but that a line of wave length 46A was observed in the third order). Among the radiations emitted from carbon, boron and oxidized boron when bombarded by electrons, he observes lines of wave length 45.3, 73.5 and 24.8 which he interprets as $K\alpha$-lines of *C*, *B*, and *O* respectively. He states that Be and Li display no *K*-lines, but it is not clear whether he actually looked for them. Searching for the $L\alpha$-line he found it in the spectra of Cr and Fe, not in those of P or S; the $M\alpha$-line in the spectra of Ta and W, not in those of Zr, Mo or Ba. The longest wave length cited is 71.5A for a *N*-line of barium. One of the essential parts of the apparatus is a screen composed of magnesium deposited on celluloid, which is more transparent to rays of this range than to visible light, and so keeps the light of the filament away from the plate.—[A. Dauvillier (Paris), CR., *182*, pp. 1083–1085, and *183*, pp. 193–195; 1926.]

KARL K. DARROW

Subject Index of the Transactions of the Optical Society.—Vols. I–XXV. By A. F. C. Pollard, Professor of Instrument Design in the Imperial College of Science and Technology, Hon. Secretary of the Optical Society of London. iv+89 pages. The Optical Society, Imperial College of Science and Technology, South Kensington, S. W. 7. Printed at The University Press, Cambridge.

This is a subject index printed on thin paper with different entries sufficiently separated to permit cutting them apart for mounting on 3×5 index cards. Each entry is classified according to the Decimal Bibliographical Classification of the Institut International de Bibliographie, of which the portion dealing with optics, light and cognate subjects has been translated by Prof. Pollard and published separately by the Optical Society. If it is desired to have both author and subject index, a second copy, in wrapper but not stitched, can be obtained at a reduced cost. All readers of the Transactions will be very grateful to Prof. Pollard for preparing this index and it would assuredly be an excellent thing if the other optical journals could publish similar lists indexed according to the same decimal system.

I. C. GARDNER

A CALORIMETRIC METHOD OF MEASURING DIELECTRIC LOSSES AT HIGH FREQUENCIES

By Gwilym E. Owen

The measurement of power losses in dielectrics at high frequencies by the usual methods, i.e., electrostatic wattmeter, resistance variation or comparison with a so-called "no loss" air condenser, involves errors due to losses in the electrical instruments used. In an effort to avoid these losses which necessarily occur in an electrical measuring system, the following calorimetric method was devised for the purpose of studying the losses in insulating materials at high frequencies.

In Fig. 1, *A–B* are two vacuum protected vessels with ground glass stoppers, also evacuated and silvered. *C* is a glass tube connecting the interior of *A* and *B* through an oil manometer *D* and by-pass stop

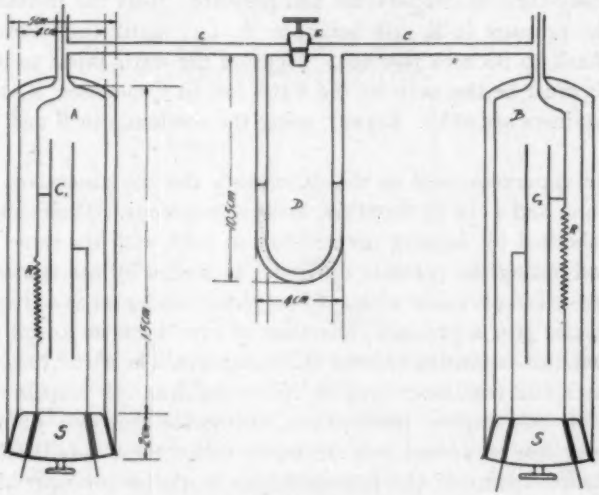


Fig. 1. *Diagram of apparatus*

cock *E*. The ground glass stoppers of *A* and *B* have two openings through which leads may be sealed in with wax. Also at the top of *A* and *B* there is an opening for a lead. The vessels are made as nearly alike as the glass blower could make them.

Two identical flat plate condensers are made of the dielectric to be tested, one for each vessel. In each container there is also a piece of

resistance wire which may be heated with a direct current. Measurements are made in two distinct ways:

(1) Condenser C_1 is made a part of a high frequency oscillating circuit, generated by a 50-watt power tube. The heat loss in the dielectric raises the temperature and pressure of the air in the container as indicated by the manometer. The pressure will increase until the heat loss through the walls of the tube is just enough to balance the heat generated. When the steady state is reached a reading of the manometer is taken. The system is then allowed to cool, after which the resistor in A is heated until the manometer shows the same pressure difference as before. If we now measure the potential drop across the resistor with a potentiometer and also measure the current, we have the power input to the resistor, which is the same as the rate of transformation of energy in the condenser.

(2) Put C_1 in a high frequency circuit as before and allow A to come to a steady state of temperature and pressure. Heat the resistor in B until the pressure in it just balances A, i.e., until the manometer comes back to its zero position. Measure the watts input to resistor B and it must be the same as the watts loss in Condenser A, as the two containers are alike. Repeat, using the condenser in B and heater in A.

In the apparatus used in this laboratory the containers are about 15 cm long and 4 cm in diameter, inside dimensions. Their similarity can be checked by heating the resistors in both with the same power input and noting the pressure difference indicated by the manometer. Test measurements made with a .05 mf paper condenser at a frequency of 10^7 cycles give a pressure difference of over 4 cm on an oil manometer, with an oscillating current of .36 amperes. The current necessary to balance the condenser loss at 10^7 cycles was .41 ampere and a change of .02 ampere produced a noticeable pressure difference. The power loss measured was .58 watts under these conditions.

A detailed report of the measurements made on commercial fiber will be made later.

RANDAL MORGAN LABORATORY OF PHYSICS,
UNIVERSITY OF PENNSYLVANIA,
PHILADELPHIA, PA.

A HIGH VOLTAGE DIRECT CURRENT GENERATOR

By S. S. Mackeown*

This note describes a source of high voltage direct current that was built to fulfill certain requirements. These requirements were that the voltage should be constant with a very small ripple, that no damage would result from a short circuit, and that the apparatus should be relatively inexpensive. The current to be drawn was very small, usually less than a milliampere. The generator was designed to operate at a maximum voltage of 50,000 volts, with an output of about 100 watts, and a ripple of less than 0.1 per cent.

The method is one of rectifying a high frequency alternating voltage. The circuit used is shown in Fig. 1, and consists essentially of a Tesla

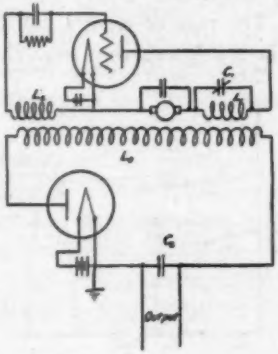


Fig. 1. *Circuit diagram.*

coil excited by a vacuum tube oscillator, the voltage across the Tesla coil being rectified. A 250 watt, three element vacuum tube[1] was used as the oscillator. The generator in the plate circuit was a 2,000 volt direct current generator. A filter of a large inductance in series, shunted by a condenser was used to suppress ripples in the generator voltage. The voltage across the large coil L_3, was rectified with a 100,000 volt General Electric kenetron. The coil L_3 was octagonal, 1 meter in length with an average diameter of 40 cm. It was wound with 100 turns of #18 double cotton covered wire. This coil together with the capacity of the kenetron has a natural frequency of about 140 kilocycles.

* National Research Fellow.

[1] This was the Western Electric type I vacuum tube and was very generously loaned by that company.

The coils L_1 and L_2 were placed inside the coil L_3, and were circular, with a diamerer of about 30 cm and had twenty turns each with taps brought out at the 10th, 15th, 17th and 19th turn. The condenser, C_1 was a variabe condenser with 14 movable plates, the distance between a pair of movable plates being approximately 1.3 cm. This condenser was immersed in kerosene oil. The condenser C_2 was a bank of Leyden jars, having a capacity of approximately .005 microfarads. By adjusting the condenser C_1, oscillations can be produced at the natural frequency of the large coil L_3.

If there is no load in the output the condenser C_2 will charge up to the maximum voltage across the coil L_3, and will be prevented from discharging by the kenetron. If there is a load in the output the condenser will discharge continuously through the load and will be charged intermittently when the voltage across the coil exceeds that of the condenser C_2. The rate of charge will be practically uniform as it is limited by the saturation current from the filament of the kenetron.

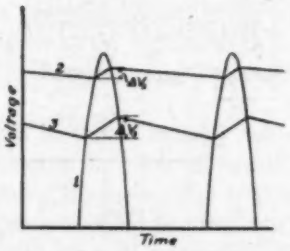


FIG. 2. *Curve 1: variation of voltage with time; Curve 2: with small output current; Curve 3: with larger output current.*

Fig. 2, shows graphically how the voltage varies with time. Curve 1, represents the voltage across the coil L_3, during the part of the cycle when the voltage is highest and in the right direction to charge the condenser C_2. Curve 2, represents the voltage across the condenser when only a small current is drawn in the output circuit. Curve 3, represents the voltage across the condenser when a larger current is drawn. In both cases the condenser charges at the same rate, but when the output current is larger, the average voltage across the condenser C is lower. The maximum ripple ΔV is $\Delta V = I/Cf$ where I is the current in the output circuit, C, the capacity of the condenser C_2, and f the frequency of oscillations in cycles per second. With a frequency of

140 kilocycles, a capacity of .005 μf and an output current of 3.5 milliamperes, the variation in voltage at 50,000 volts is .01 per cent. This is a higher current output than the present set would furnish at that voltage.

There is another source of ripple which is independent of the output current. This is due to the fact that the kenetron has some capacity. Since the voltage across the kenetron and condenser C_2 is $V_0 \sin \omega t$ the alternating voltage across the condenser C_2 will be $C_k V_0 \sin \omega t / (C_k + C)$ where C_k is the capacity of the kenetron. Assuming the capacity of the kenetron to be $5\mu\mu f$, this ripple will be approximately 0.1 per cent if C is $.005\mu f$. It is necessary that the filament side of the kenetron be grounded in order to prevent the capacity of the filament batteries to ground from shunting the capacity of the kenetron and thus materially increasing this ripple.

Any variation in the voltage furnished to the plate of the oscillator will be reproduced in the high voltage output, since the voltage across the coil L_3 is proportioned to the plate voltage. In the present apparatus the greatest variation in the high voltage has been due to this cause.

With the apparatus described above voltages as high as 60,000 were obtained. The voltage was limited by corona losses from the coil L_3. The maximum output was approximately 2 milliamperes at 40,000 volts. As these values were sufficient for the work on hand no special effort was made to obtain the greatest possible output. In case of short circuit the discharge is limited to the energy contained in the condenser C_2.

This method of obtaining high voltage would not be feasible if any large amount of power were desired. This is due to the fact that only a limited current can pass through the kenetron and this current can flow only for a small part of the cycle. The regulation is also poor, as the voltage decreases quite rapidly as the current increases. However, if the current is kept constant, the voltage will vary only as outlined above.

For certain work where small current at high voltage is desired and it is imperative that the voltage be free from ripples, an arrangement of this kind should prove satisfactory.

CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA.

Chemical reactions induced by β and γ rays.—The method employed by Henri and Errera for noting and following the chemical changes produced by irradiating a gas consists in photographing the absorption spectrum of the gas at intervals during the irradiations. If, for instance, the bands of a new substance gradually appear, its amount at any stage of the process is determined by comparing the photograph with a preliminary set of photographs taken with different known concentrations of that substance in the tube. This method has the great advantage that the measurements involve no disturbance of the condition of the irradiated gas (unless, of course, the light projected upon it for producing the absorption spectrum should have some effect). The most favorable case was that of benzene mixed with air, in which irradiation with the β and γ radiations of radium caused phenol to appear, as the emergence of its characteristic bands disclosed. Determining in the stated way the amount of phenol produced by a given irradiation, and determining separately the numbers of ions produced by the same irradiation in a quantity of benzene and in a quantity of air equal to the quantities of these gases in the original mixture, Errera and Henri find that 60 times as many molecules are formed in the mixture as there are ions formed in the individual gases which constitute it. (It is implied, of course, that the number of ions formed by irradiation in either gas is independent of whether the other is mixed into it). Similar experiments with other gases mostly gave blank results.—[J. Errera and V. Henri (University of Zürich); J. de Phys. (6), *7*, pp. 225–229; 1926].

KARL K. DARROW

Depolarization of resonance radiation by magnetic field.—The data heretofore assembled bearing upon the effect discovered by Wood and Ellett (the influence of magnetic field upon the degree of polarization of resonance radiation excited by mercury vapor) agree with the undulatory theory and with equivalent quantum theories in all but one case: viz., the precise dependence of the effect upon magnetic fieldstrength when the magnetic field is parallel to the direction of the observed beam of resonance radiation and normal to that of the electric vector. This remaining disagreement is eliminated by Keussler by means of observations upon λ2536 with a method which (he claims) is better than the previously used methods of measuring degree and plane of polarization of the partially polarized beam; in his experiments, a photoelectric cell is used to measure the intensity of the beam after transmission through a Nicol set successively at various azimuths. The data agree well with the theory, and require, for the half-period of the postulated oscillating electron, a value of the order of 10^{-7} second; the exact value depending on whether the Larmor value of the precession, or a multiple thereof, be used.—[V. von Keussler (Munich), Phys. ZS., *27*, pp. 313–316; 1926.]

KARL K. DARROW

AN IMPROVED ELECTRIC FLOW METER

By Thomas R. Harrison

With the great advancement which has taken place in engineering practice, realization of the importance of making systematic and accurate measurements of the conditions and quantities involved has grown rapidly. At the same time, the desirability of locating the meters at points of greatest convenience to the users is more keenly appreciated today than ever before. An example of this trend is supplied by the popularity of flow meters of the electrically operated type by the use of which an indicator may be located in clear view of the boiler fireman as a guide in firing, with the recorder and integrator placed at a convenient point among a group of recording instruments. Also, from another point of view, electrical operation is especially advantageous for flow meters, since it affords a means for producing external indications and records of conditions existing inside of a high pressure steam or water pipe, without transmission of mechanical motion—as for instance, by means of a rotating shaft, passing through a pressure-tight packing gland, which of course would be essential and would necessarily cause serious friction losses. Naturally, however, when electrical means are introduced to avoid the objectionable features of a mechanically-operated instrument, other undesirable features are likely to be introduced unless careful planning is applied to all phases of the question.

Because of these considerations, the new Brown electrically operated flow meter deserves the special attention of all engineers interested in flow measurement, since by a novel, but thoroughly practical utilization of a well-known electrical principle, the design of the Brown Electric Fow Meter at one stroke avoids the electrical as well as mechanical difficulties previously encountered in flow meters. Among the characteristics of this new line of instruments are the following notable features:

1. The readings of the instrument are fundamentally independent of the value of the voltage impressed upon the electrical system. The instrument reads correctly, while operating on varying line voltages without the use of either voltage regulators or compensators.

2. The electrical circuits at the manometer, indicator and recorder consist simply of stationary, divided, inductance coils. These have only three connections which are permanently made at the time of

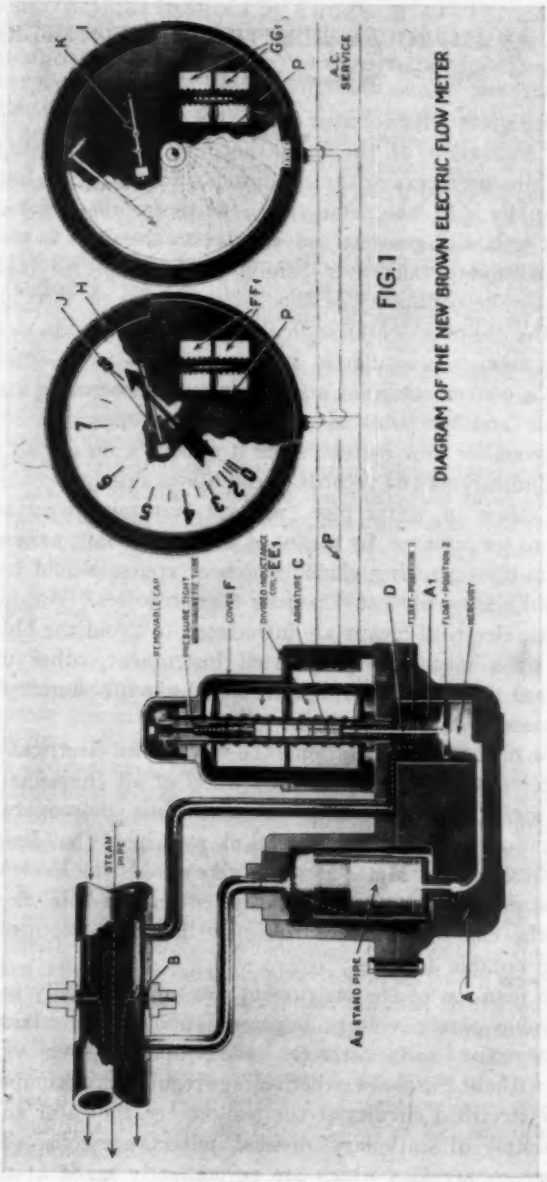


FIG. 1

DIAGRAM OF THE NEW BROWN ELECTRIC FLOW METER

installation. There are no make-and-break contacts, such as contacts dipping into mercury within the pressure chamber, voltage regulator contacts or similar devices.

3. In the manometer, or meter body, all electrical windings and connections are entirely external to the pressure chamber.

4. The integrator is a mechanical device operated by the electric clock which drives the charts. An equal amount of power is available for operating the integrator at all rates of flow, making possible the use of the most easily-read type of 5-figure counter for the integrator.

5. A pen operated by the action of the integrator mechanism makes a record at the outer edge of the chart each time the integrator mechanism increases the counter reading by one unit. Each tenth mark is distinguishable from the intermediate marks in order to facilitate counting when it is desirable to determine the total flow for a day, or during any hours of the day, without having to watch the counter.

6. The entire integrator mechanism with its individual recording pen is so simple and compact that it can be mounted in the standard recorder case along with the recording mechanism, thus avoiding the necessity of a separate integrator case.

PRINCIPLE OF OPERATION

As shown in Fig. 1, manometer A operates in response to differential pressure caused by flow of the fluid through an orifice B. When the rate of flow increases, mercury is depressed in chamber A_1 and rises in chamber A_2, the difference in mercury level in the two chambers being a measure of the rate of fluid flow through the orifice in accordance with well-known principles. When the flow increases from zero to a maximum value, a float which rides on the mercury surface in chamber A_1 is lowered from the position indicated by dotted lines to a lower position as indicated by the solid lines. The float is made of non-corrosive metal and chamber A_1 has a moulded bakelite lining, ribbed on the inside, insuring freedom of action at all times. An armature C of transformer iron is supported by the float on a non-magnetic rod D and the armature is raised and lowered in accordance with the motion of the float.

This armature travels inside of a rust-proof, non-magnetic tube which has high electrical resistance and great mechanical strength. The pressure of the fluid being metered is confined within this tube and the electrical inductive winding EE_1 which is slipped over the outside of the tube has excellent magnetic linkage with the armature

which moves inside. At the same time, the coil is under atmospheric conditions only and is protected by a cover F.

The outer ends of the divided winding EE_1 are connected directly across the service mains of an alternating current supply line and connections are run from these ends directly to the outer ends of a similar divided inductance coil FF_1 which operates an indicator H and also to divided inductance coil GG_1 operating a recording instrument I. Armatures are hung on counterbalanced arms J and K in the two instruments. The points of connection between the two parts of divided coils EE_1, FF_1, and GG_1 are all connected together by a neutral wire P and when thus connected the coils form the self adjusting inductance bridge which is the outstanding basic feature of this flow meter.

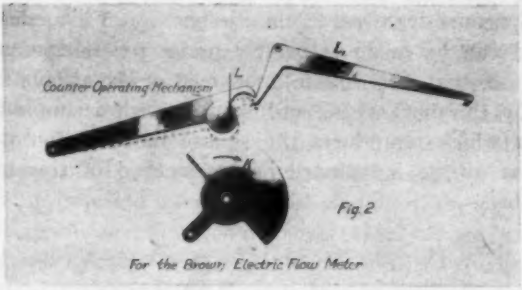
When the armature in the manometer is raised or lowered by a change in fluid flow, the relation between the voltages across the two parts E and E_1 of the winding will be changed. This causes the currents in the two parts FF_1 of the indicator coil, and also the currents in the two parts GG_1 of the recorder coil, to become unequal, as a result the armatures of the indicator and recorder move to new positions corresponding to the position of the armature C and the meter readings are adjusted accordingly by means of the gearing or linkage shown.

More briefly, the operation of the inductance bridge may be summarized by saying that the armatures of the instruments move in accordance with the motion of the manometer armature as the latter is moved up and down by the mercury float. Since the positions assumed are such that the relative voltages across the two parts of each coil are the same, the operation of the instrument is independent of the actual value of the line voltage. No current flows in the neutral wire and the currents in the two halves of each divided coil are equal except when the armatures are being moved.

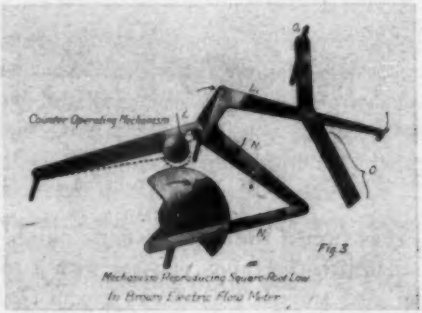
THE INTEGRATOR

In order to make use of the simple inductance bridge method of operation, a special type of integrator was developed which increases the counter readings in proportion to the square root of the angular deflection of the recorder pen arm, this being the relation of flow to the pressure difference across the orifice. Attached to the gear train which drives the recorder chart is a sector of a disc K, Fig. 2, which rotates at a constant rate. A roller L is normally held up by

latch L_1, out of contact with the sector. The latch is tripped when the sector is in different positions, depending upon the rate of flow, and the roller is rotated through an angle proportional to the rate of flow before the sector passes out of contact with it. After the sector



passes beyond the roller the latter is again latched up by L_1 and the process repeated at regular intervals. The square root relation existing between rate of flow and pressure difference (the latter being translated into recorder pen travel) is reproduced in the relation between angular travel of disc L and pen deflection by means of the



oscillating latch carrier N being driven by the rotating sector K, through a link N_1 shown in Fig. 3. Tripping blade O which is attached to the recording pen shaft O_1 releases the latch at the proper point, according to the reading of the instrument, the motion of the pen never being restricted by the tripping operation.

The angular relation between the uniform rotation of sector K and the rocking motion of arm N is an almost exact reproduction of the

square root law through a large portion of the downward motion of arm N and a slight departure from the exact relation desired is taken care of by the shape of tripping blade O. A roller on the end of arm N passes across tripping blade O, which is very thin, and holds O fast against a plate while latch L_1 is being tripped.

Two important features of this design are: First, the parts are simple and can be made accurately under practical manufacturing conditions so that the square root relation is always reproduced correctly by the mechanism; and, second, such a simple integrating mechanism which reproduces the square root relation permits the employment of the inductance bridge method of transmitting the meter readings.

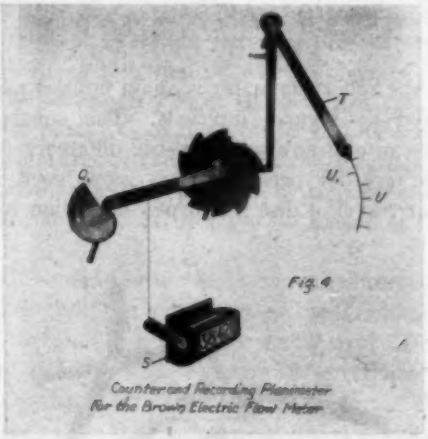


Fig. 4

Counter and Recording Planimeter for the Brown Electric Flow Meter

When roller L has turned through a definite number of revolutions a pawl is released which thereupon engages with a toothed pinion of the chart-driving gear train. This causes a cam Q, Fig. 4, to make one complete revolution after the pawl is released and the cam then remains at rest until the roller again completes the proper number of revolutions. As the cam Q advances, a cam arm R is gradually raised, lifting the arm of ratchet counter S until the high point Q_1 of the cam passes, then the cam arm falls quickly and advances the reading of the counter by one unit without allowing the figures to pause in a half-way position difficult to read. Each time the cam arm falls the recording planimeter pen T makes a jog U in its record line,

every tenth jog U_1 being in the opposite direction to facilitate counting when desired. The five-figure integrator dial S can be read at any given hour or hours of the day, and records made on the chart or elsewhere if desired; but the record of the recording planimeter can take the place of these counter readings and affords the added advantage of making a record from which the total flow can be read off for any desired fraction of a day at any subsequent time which may be convenient—eliminating the necessity of having an observer on hand at the proper hours to note the readings of the counter as they occur.

A series of printed charts are chosen with a fixed ratio between successive ranges. The manometers also are arranged to be adjusted for several appropriate ranges. This simplifies the choice of an orifice plate, the size of which depends chiefly upon the density of the fluid and the pipe size. With such an orifice the apparatus is easily adjusted for successive chart ranges by using a stand-pipe of proper size in the manometer. This is useful where the average load changes from time to time, for then the apparatus can be readjusted by changing the manometer stand-pipe—instead of changing the orifice plate which is much less convenient.

The various manometers for use with steam, operate on successive maximum pressure differentials increasing by intervals of about 60%, ranging from 1.6 inches to 16 inches of mercury. There are six ranges in this series, the choice of a suitable manometer depending upon velocities encountered. Any manometer of the series, however, may be converted into the most sensitive one by simply opening a valve. This adapts the meter for use with one of the lower range charts, making it easily convertible for low load periods, which will be a distinct advantage in many types of service.

Where the apparatus must work on very low pressure differentials an especially sensitive type of manometer is provided, the most sensitive of which gives full deflection of the meter on a pressure difference of $\frac{1}{2}''$ of water, although the operating force of the meter mechanisms of this high-sensitivity series is as great as that of the high-range manometers.

The simple inductance bridge principle upon which all of these instruments operate, their freedom from troubles obviated by electrical connections that are permanent and external to the pressure chamber, their independence of voltage fluctuation, their automatic recording planimeters, the adaptability with which their manometers handle various ranges, their easy reading 5-figure integrating counters, the

compactness of their operating units—the advantages of all of these various features make this new flow meter especially desirable for measuring the flow of steam, water, gas, air and other fluids, and of exceptional interest to all power plant and industrial engineers and officials concerned with such measurements.

THE BROWN INSTRUMENT COMPANY,
PHILADELPHIA, PA.

Magnetostriction in permalloy.—Measurements of elongation (or contraction) of wires of iron, nickel and seven alloys of these two (the percentages of nickel by weight having the values 45.57, 64.44, and five others between 74 and 90) were made by an extremely delicate method competent to detect length-changes amounting to 4A in a portion of the wire 12 cm long. The method is a variant of the usual optical-level method: the beam of light falling upon the mirror at the end of the lever has previously passed through the transparent strips of a transmission grating, and after reflection from the mirror it must pass through the grating again before reaching the photoelectric cell by which its intensity is measured; a slight displacement of the mirror, produced by a slight change in the length of the wire to which the other end of the optical lever is clamped, suffices to shift the reflected beam sidewise across the grating to such an extent that the proportion of light stopped by the opaque strips is perceptibly altered. (A change in the temperature of the specimen amounting to 0.001°C produces 50 times as great a strain as the least measurable one). Measurable changes in length occur in some alloys with fields as low as 0.17 gauss; this lends additional importance to the demonstration that in some cases, as that of iron, the magnetostriction is not appreciable until the applied field attains several gauss and the magnetization a considerable fraction of its saturation-value, thereafter increasing at an accelerated rate over a certain range of field strengths. The curves show the length of the wire to be decreased by magnetic field if the proportion of nickel exceeds 81%, increased otherwise. Iron exhibits maximum elongation when applied field $H=17$, ferric induction $B-H=15700$. With each alloy the length increases steadily, or decreases steadily, until saturation is attained; then the length ceases to change. In the series of alloys, the dependence of maximum observed magnetostriction upon weight-percentage of nickel is shown by a curve consisting of two nearly straight arcs meeting at a slight angle near percentage 75. The value for pure iron lies quite away from this curve, a fact which may be correlated with the discrepancy between its atom-lattice and those of all the other substances investigated. Tension has interesting effects: it diminishes the elongation imposed by the magnetic field on the 74% nickel alloy, increases the contraction of the 84% alloy, and converts into an initial contraction the initial indifference to magnetic field displayed by the 80% alloy.—[L. W. McKeehan and P. P. Cioffi (Bell Telephone Laboratories); Phys. Rev. (2), *28*, pp. 146–157; 1926.]

KARL K. DARROW

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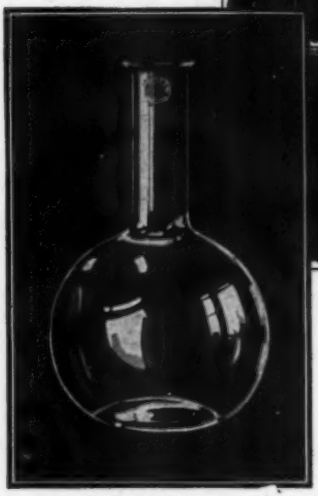

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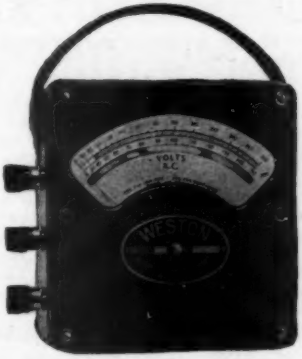

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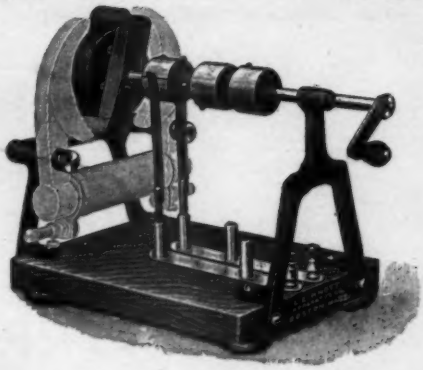

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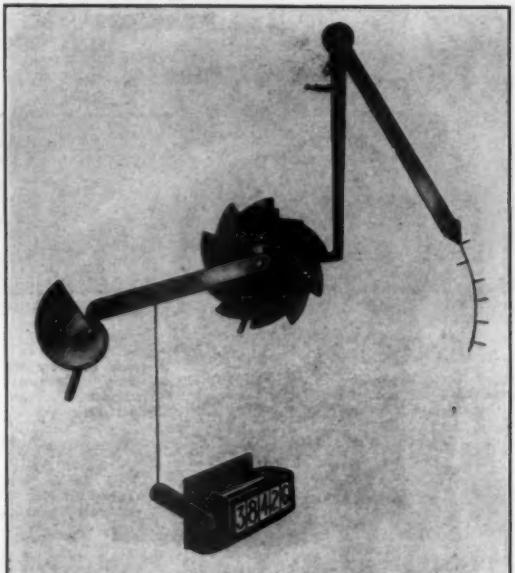

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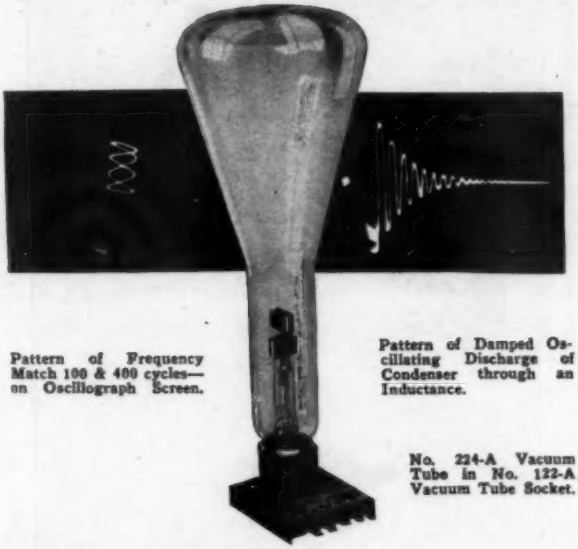

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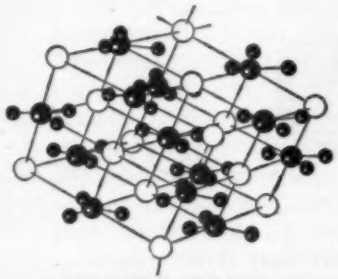

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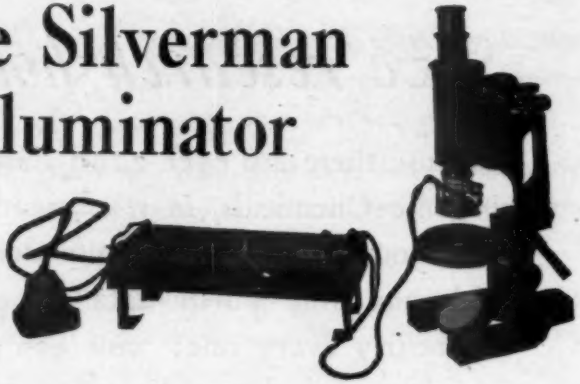

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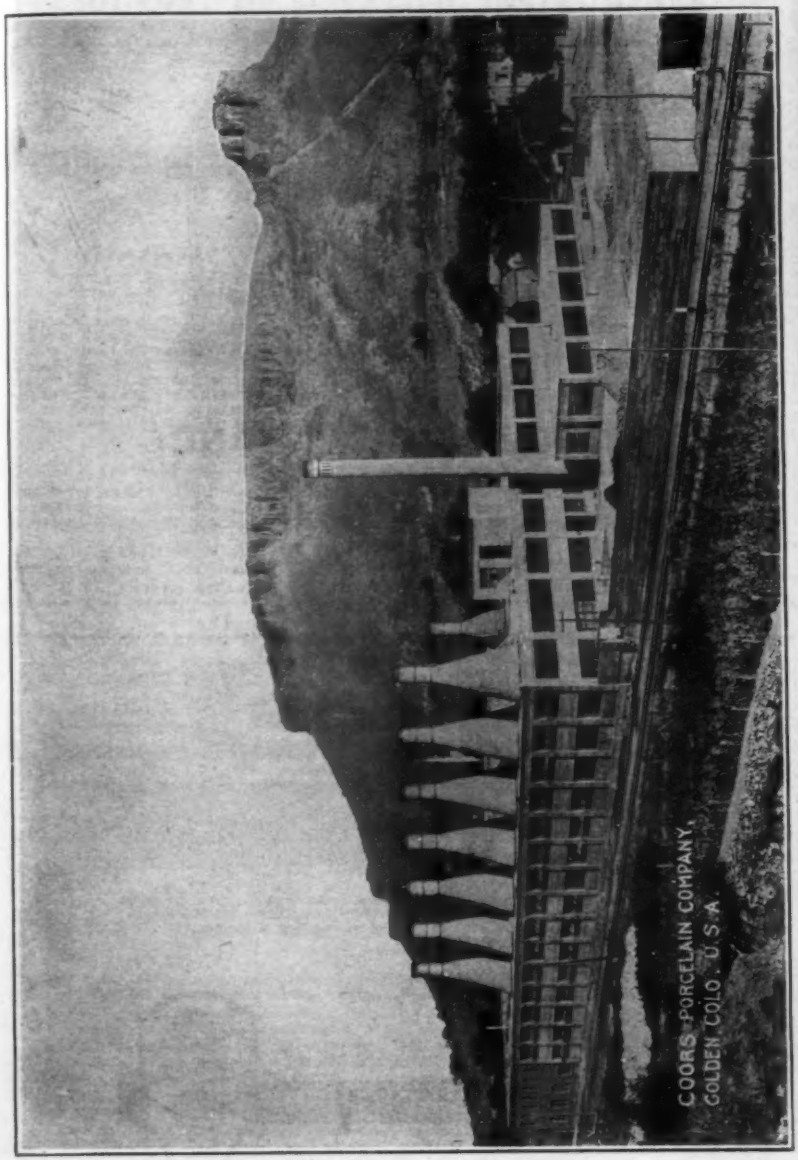
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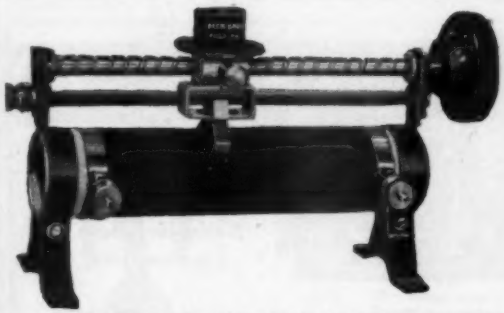

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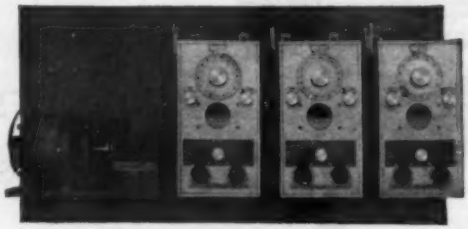

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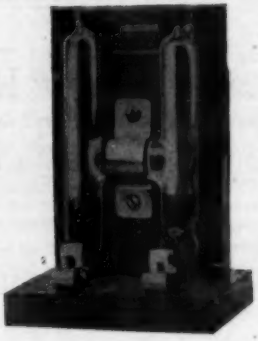

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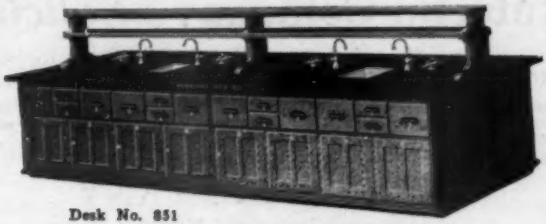

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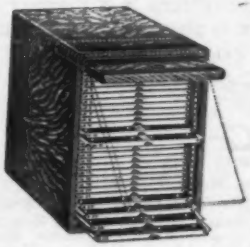

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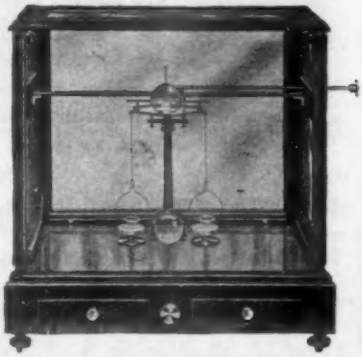

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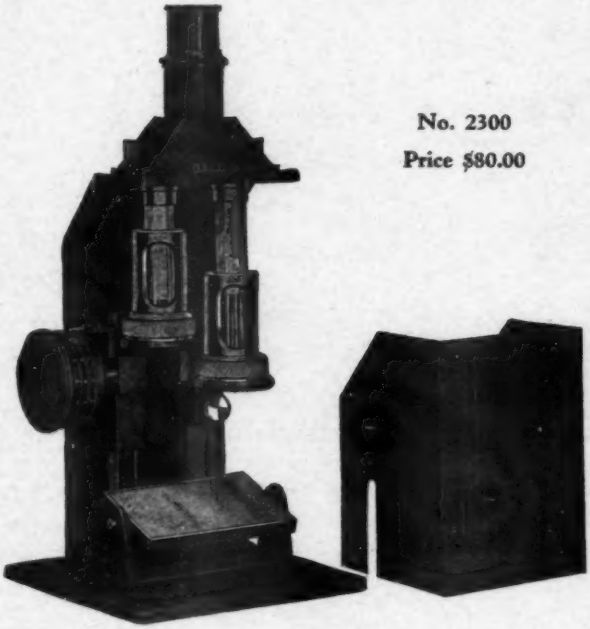

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